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MERCHANT SHIP SIGNATURES (U)

Jack A. Shooter
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18 August 1977

Technical Report

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Ship signatures in the form of 1/10 octave band time series and narrowband spectra (0.15 Hz resolution) over the frequency range 10 to 500 Hz are presented. These signatures, detected on a near-bottom receiver in the mid-northeast Pacific Ocean during the CHURCH OPAL exercise, are characterized by greater than 20 dB signal-to-noise ratios over the entire frequency band of 10 to 500 Hz for all merchant ships that approached the receiver site to within 10 nm. The high signal-to-noise ratios resulted from very low noise (C)

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levels observed in this ocean area. Estimates of source level based on reported ship positions and theoretical propagation loss are 10 dB greater than expected, based on the earlier measurements of Ross and Alverez. (C)

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Thank you very much.

Yours truly,

Dila Davis

Dila S. Davis

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I. INTRODUCTION

(C) During the LRAPP sponsored exercise, CHURCH OPAL, an ACODAC system, was deployed to record ambient noise levels in the water column between near critical depth and the ocean bottom.[1] In addition to the background ambient noise, recordings were made of the signatures of several merchant ships, which passed within a few nautical miles of the ACODAC hydrophones. As a result of low ambient noise levels near the ocean bottom, these ship signatures at closest point of approach (CPA) dominated the entire frequency spectrum over the band 10 to 500 Hz. Four of these merchant ships were selected for detailed analysis; all four were typical in that all were approximately 147 m (500 ft) in length and were traveling at speeds of advance (SOA) near 7.7 m/sec (15 kt). These values are comparable to the parameters for a standard merchant ship established by Ross and Alvarez.[2]

(U) This paper presents the characteristics of these signatures in the form of 1/10 octave band time series and high resolution (0.146 Hz) spectral plots. The second section discusses general observations of the data, including the measurement procedures. The third and fourth sections present estimates of source level and error analyses based on measurement system accuracy, source range, and propagation loss (PL). The details of the range estimate at CPA and the PL algorithm are presented in separate appendices. Four appendices (A, B, C, and D) summarize detailed looks at the four ship signatures before, during, and after CPA.

(U) Three important points are made in this paper.

(C) (1) As a result of "mode stripping" and bathymetric shielding at the CHURCH OPAL site, the background noise field due to distant shipping diminishes 20 dB in level from near critical depth to near ocean bottom. This allows for the observation of broadband, high signal-to-noise ratio (S/N) (20 to 30 dB) measurements on ship generated sound fields that approach to within ranges of 20 miles.

(C) (2) The ship radiated sound field is clearly asymmetric; more energy is radiated astern than is radiated forward.

(C) (3) The estimated source levels, at 25 Hz, for the four ships analyzed in this paper, are on the average 10 dB higher in level than the data presented by Ross and Alvarez[2] and data presented in a more recent NAVOCEANO[3] report.

II. GENERAL CHARACTERISTICS OF THE DATA

A. Measurement and Analysis Techniques

(C) The CHURCH OPAL measurements analyzed in this paper were made in September 1975 in deep Pacific water at a location of 27°40.73'N and 137°55.00'W. The ACODAC was configured with a vertical string of 13 hydrophones extending from above critical depth to approximately 30 m from the bottom. The data reduction for the purpose of this report used four of the hydrophones, which ranged from near critical depth to near bottom, as shown in Table I.

(U) Events which occurred during the measurement period have been correlated with ship traffic near the ACODAC site. This was possible due to the ship tracking information which was supplied in the form of ship's reports by Fleet Numerical Weather Central[10] (FNWC). Each ship track is identified, in this document, by the ship's radio call sign.

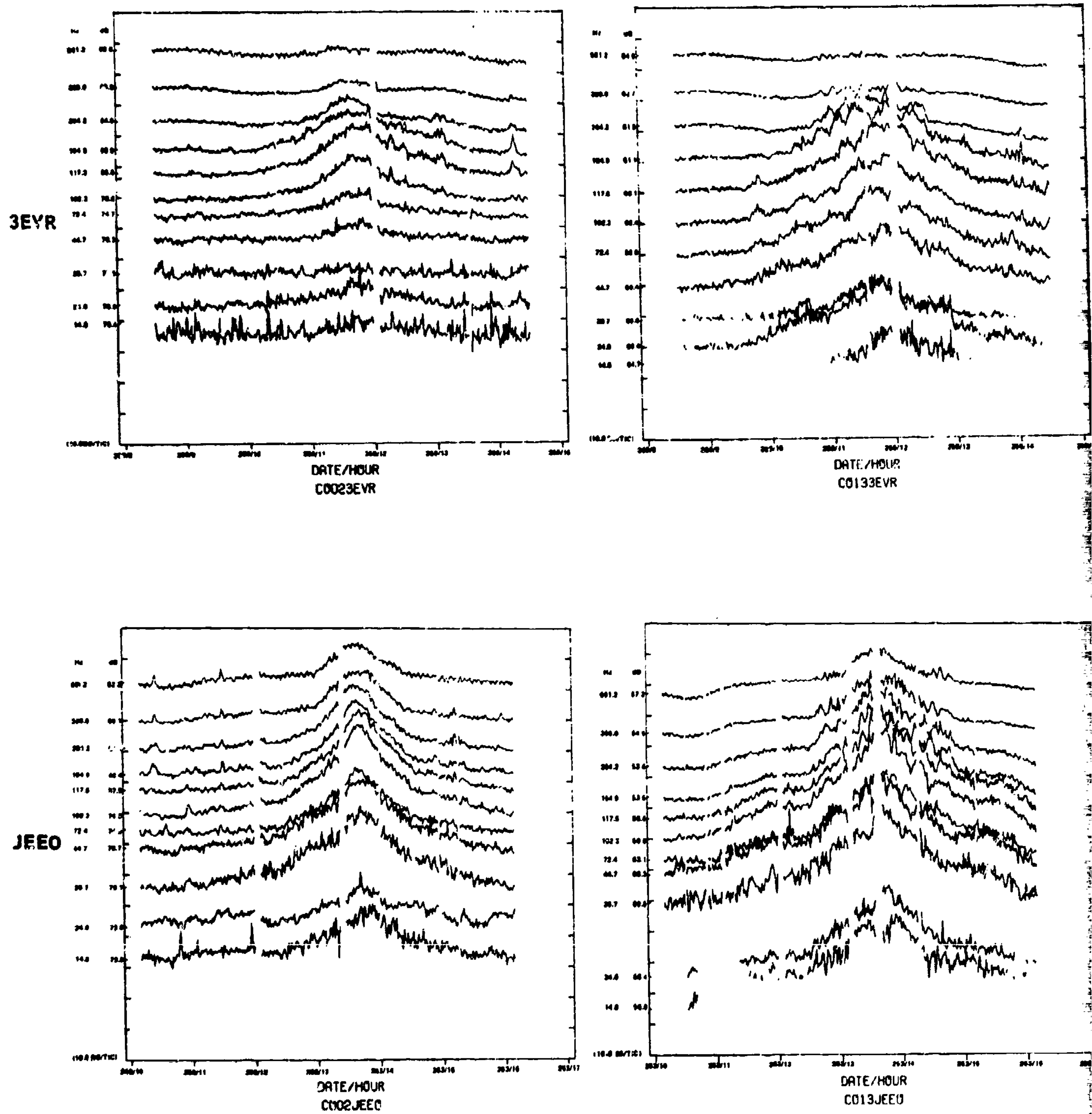
(U) There are two primary components of surface ship generated noise[6] and each must be considered in the characterization of an event. The first is a wideband component related to the ship's propeller cavitation. This continuous spectrum is presented using time series plots of sound pressure level for selected 1/10 octave frequency bands. Examples of these plots are shown in Fig. 1. Each plot covers a time period for 7 h; each tick mark on the horizontal scale represents 1 h. The two numbers listed to the left of each band are the 1/10 octave band center frequency and its sound pressure level at the initial time of the plot.

(U) The second primary spectral component of surface ship generated noise is a collection of narrowband lines which can be the result of several mechanisms. The most pronounced lines are at the propeller blade rate and its associated harmonics, which result from the modulation of the

(U) TABLE I

ACODAC HYDROPHONE LOCATION RELATIVE TO CRITICAL DEPTH AND BOTTOM

	Water Depth (m)	Distance from Bottom (m)
Hydrophone 02	3459	1420
Critical Depth	4089	790
Hydrophone 07	4459	420
Hydrophone 09	4681	200
Hydrophone 13	4853	30
Bottom	4883	--



HYDROPHONE 02
RECEIVER DEPTH: 3459 m

HYDROPHONE 13
RECEIVER DEPTH: 4853 m

FIGURE 1
TIME SERIES PLOTS (U)

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(U) cavitation bubble field by inflow to the moving propeller.[7] Additional mechanisms which contribute narrowband lines at primary and harmonic frequencies are the propeller shaft rotation, main propulsion diesel firing or turbine rotation, and other machinery on board the ship. These narrowband components have been analyzed using narrowband spectral plots for each event over the frequency range of 10 to 500 Hz. Since the narrowband spectra are generally unique for each event they have been termed ship signatures. Examples of these signatures are shown in Figs. 2 and 3 for events 3EVR and JEEO, respectively. In each case, the resolution was chosen to be 0.146 Hz with an integration time of 10 min. The integration time was sufficiently short so that no significant changes in the character of the sound generator occurred during the integration period. The vertical scale on each of these plots is calibrated in dB re 1 $\mu Pa/Hz^{1/2}$.

B. Depth Effect

(C) As stated in the introduction, high S/N ship signatures obtained from the CHURCH OPAL exercise were partially due to a decrease in the distant shipping noise level as a function of depth in the water column due to mode stripping. The two events shown in Fig. 1 are due to ships which have been identified as 3EVR (GREAT SUCCESS) and JEEO (KANESHIZU MARU). GREAT SUCCESS was an Armenian general cargo carrier with 8400 brake horsepower (bhp) and KANESHIZU MARU was a Japanese bulk carrier with 9400 bhp. Two time series plots (including CPA) for each event are presented in Fig. 1. Each ship was traveling at a speed of advance near 15 kt; thus the time scale corresponds to about 15 nm per tick mark. The wind speed during the transit of 3EVR was near 15 kt and was almost 10 kt during the transit of JEEO. One immediate observation is that wind generated noise was masking part of the high frequency spectrum of 3EVR, even at CPA. When these spectra are viewed as a function of depth in the water column, it is obvious that the background noise due to distant shipping is much lower on the near bottom hydrophone. When the radiated sound field from the event dominated the spectra, the

(C) S/N on the deeper hydrophones was much higher. This behavior was first clearly documented in 1976 in a report by Wittenborn[1] and was termed depth effect. In the earlier report "distant" is defined to be in excess of 150 nm from the receiver so that no single sound source dominates the spectra.

(C) An example of depth effect from event 3EVR can be observed in Fig. 1. This figure shows the 44 Hz band on hydrophone 02 with a background noise level near 76 dB//μPa/Hz$^{1/2}$ whereas the background noise level on hydrophone 13 is near 59 dB//μPa/Hz$^{1/2}$. At CPA, 3EVR is causing a level near 80 dB on both hydrophones; this yields an S/N of 6 dB on hydrophone 02 and an S/N of 20 dB on hydrophone 13, the near bottom hydrophone. For event JEEO, also shown in Fig. 1, a background level of 74 dB//μPa/Hz$^{1/2}$ is indicated for the 44 Hz band on hydrophone 02 and 58 dB//μPa/Hz$^{1/2}$ is indicated on hydrophone 13. At CPA, both hydrophones indicate a level near 102 dB; this yields an S/N of 28 dB on hydrophone 02 and an S/N of 44 dB on hydrophone 13.

C. Aspect Dependence

(C) As stated in the previous section, the continuous cavitation spectrum of a passing ship can be analyzed using the time series plots of 1/10 octave frequency bands. In addition to the depth effect, a second observation which can be made from Fig. 1 is that most of the 1/10 octave bands below 200 Hz are asymmetric with respect to the ship's CPA. This frequency dependent asymmetry indicates that more low frequency energy is being radiated astern than is being radiated forward. This is in general agreement with previous studies[3] which have shown a definite null at a ship's bow due to hull radiation patterns.

(C) For event JEEO in Fig. 1, the aspect angle from ACODAC to ship was near 0° before CPA and near 180° after CPA because the ship passed directly over the hydrophone string. However, for events with greater CPA ranges, such as event PIRN described in Appendix C, the aspect angle

(C) never approaches 0° at close range and the asymmetry is still present in the continuous spectral plots, particularly at the lower frequencies. This indicates that hull radiation patterns are not entirely responsible for the sound field asymmetry. Other mechanisms, such as the distributed sound from wake noise, may be an equally important factor. The effects of this asymmetry will be noted later in this section in the discussion of ship signatures.

D. Bottom Interference

(C) Again based on Fig. 1, a third observation can be made in addition to depth effect and sound field asymmetry. A definite change in the character of the time series plots on the near bottom hydrophone is observable. For event 3EVR, this figure shows the 102 Hz 1/10 octave frequency band sound pressure level on hydrophone 02 to be increasing smoothly before CPA and decreasing smoothly after CPA, although asymmetry is apparent. However, following the same 102 Hz band for hydrophone 13, the received sound pressure level exhibits anomalous behavior in the vicinity of CPA. Similar behavior is also apparent for event JEEO and is most clearly noticed in the 14.8 Hz band. As presented in the appendices, it is clear that this near-bottom interference behavior occurred for each documented event.

E. Ship Signatures

(U) As stated previously, the second primary component of surface ship generated noise consists of narrowband spectral lines at specific machinery rotation rates and their associated harmonics. The CHURCH OPAL data are thus also analyzed in this report using narrowband spectral plots in the frequency range of 10 to 500 Hz. The narrowband spectra plotted in Figs. 2 and 3 represent a CPA sequence for two separate events. Figure 2 presents data for event 3EVR for hydrophones 02 and 13. Figure 3 presents data for event JEEO for the same two hydrophones. Three plots are presented for each hydrophone in a 2 h sequence, beginning with a time slice 1 h before CPA, followed by a slice at CPA,

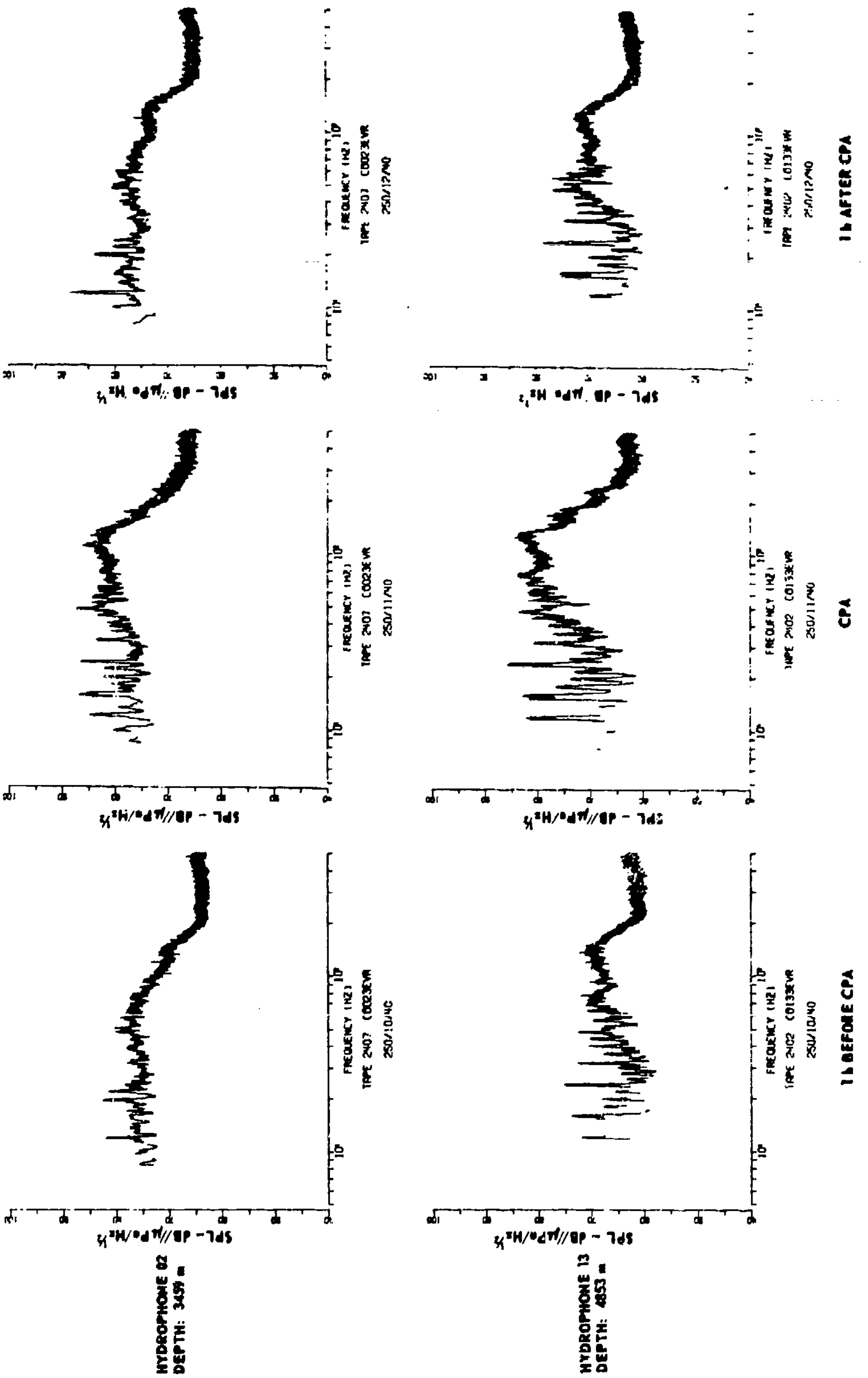

FIGURE 2
3EVR SIGNATURES (2)

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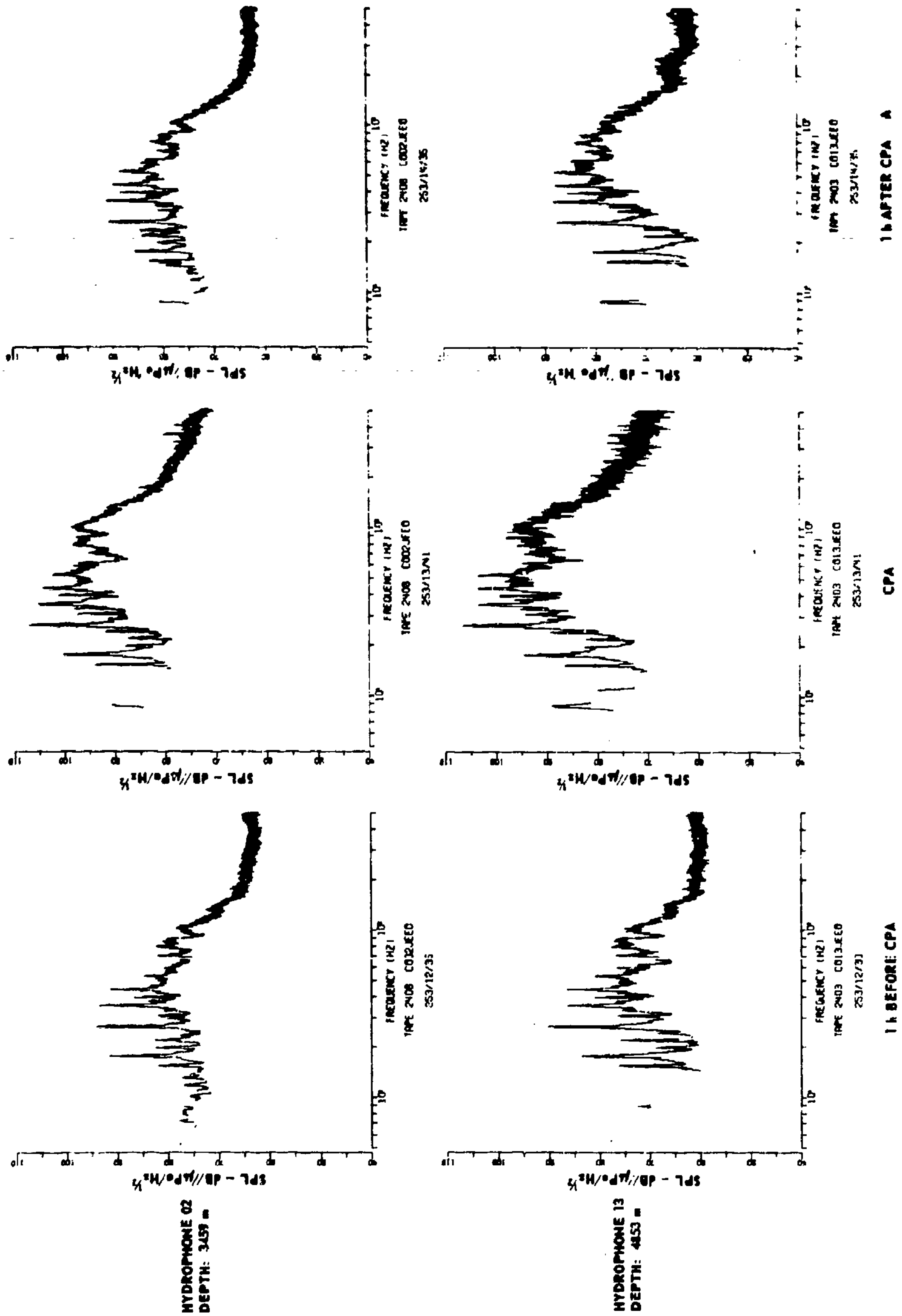

FIGURE 3
JEEO SIGNATURES (U)

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KRP - DR
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(U) and concluded by a time slice 1 h after CPA. Each plot is a 10 min spectral average with the beginning time shown at the bottom of each plot. The frequency resolution in each case is 0.146 Hz.

(U) The main feature of each of these sequences is the dramatic increase in signal level which occurs at CPA and is best observed for frequencies between 60 to 200 Hz. This effect seems to be independent of receiver depth but is highly range dependent. Examination of the signatures of other events indicates a similar behavior at CPA.

(C) Additional evidence of depth effect is again apparent in the signatures of these events. The broadband noise level is generally lower on the deep hydrophone. The nominal 24 Hz line for event 3EVR exhibits an approximate 6 dB S/N improvement from hydrophone 02 to hydrophone 13. However, the higher frequency portion of the 3EVR spectrum is being masked by wind noise even on the deep hydrophone. As noted previously, the wind speed during the passage of 3EVR was approaching 15 kt which represents the transition into a region where locally generated wind noise is dominating throughout the water column.[1,5] This contrasts with the passage of JEEO where wind speed was below 10 kt and depth effect was evident at all frequencies. If the nominal 26.5 Hz line for event JEEO is considered, an approximate 5 dB S/N improvement is evident between the signature from hydrophone 02 and the signature from hydrophone 13.

(C) A detailed examination of the signatures presented in Figs. 2 and 3, and again in the appropriate appendix, indicates additional evidence of the radiated sound field asymmetry discussed previously. In Fig. 3, for event JEEO, the broadband noise level for hydrophone 13 appears to be about 5 dB higher 1 h after CPA versus 1 h before CPA. The nominal 26.5 Hz line for the same sequence appears with an S/N of 20 dB both 1 h before CPA and at CPA but the same line appears with only 15 dB

(C) S/N after CPA. A small Doppler shift from higher to lower frequency for this line from before CPA to after CPA is also evident.

(C) One additional observation which is important in reducing the available data is that the character of the local ship signatures shows no distinct qualitative dependence on either depth or range. Although S/N may change as a result of depth effect and asymmetric sound field generation and Doppler shift may slightly shift the major spectral components, the quintessence of the signatures is unchanged. This is an observation which may greatly reduce the quantity of data which must be analyzed. It may thus permit propagation modeling to yield accurate source level and source characteristic information.

(C) In summary, the following observations apply to the ship signatures presented in this paper.

(1) The absolute SPL increases at CPA and is most visible in the frequency range of 60 to 200 Hz.

(2) The radiated sound field asymmetry results in increased S/N after CPA.

(3) Depth effect clearly discriminates against distantly generated noise on the deep hydrophones.

(4) Depth effect is masked when locally generated wind noise dominates the spectra as wind speed exceeds 15 kt.

(5) Doppler shift is evident for all local ship signatures.

(6) The character of the signatures is essentially independent of both depth and range, except for the previously noted effects.

III. ESTIMATION OF SOURCE SOUND PRESSURE LEVELS

A. Source Level Computation

(U) Section II of this paper outlined the data reduction techniques required to present the CHURCH OPAL data from four events in a form suitable for signature analysis. This section outlines a method used to make a preliminary estimate of source sound pressure levels from the four events based on a theoretical propagation loss calculated at 25 Hz. The sources of possible errors in this method are enumerated at the end of this section along with an estimate of the magnitudes of each possible error. Section IV presents the results of the source spectrum levels using the methods discussed in this section; the results are quantitatively compared to the results obtained by Wittenborn[1] and Ross and Alvarez.[2]

(U) A 3-step procedure is used to estimate source spectra. The first step is to obtain valid received narrowband spectra, as outlined in section II. The second step is to obtain a suitable theoretical transmission loss curve as a function of range from the source. The third step is to correlate the received narrowband spectra to a specific source-to-receiver geometry so that the transmission loss curve can be used to predict source sound pressure levels.

(U) To develop a suitable and concise method of generating a theoretical transmission loss curve for step 2, an acoustic normal mode model was chosen. In the bottom interaction project at ARL:UT, one of the tasks required developing a low frequency, deep water, normal mode model. The model, described in Appendix E, incorporates a detailed subsurface composition description and an arbitrary sound speed profile.

(U) To demonstrate curve fit, Fig. 4 presents the propagation loss predicted by the ARL:UT normal mode model superimposed upon actual received SPL data as a function of range for event JEEO.

(U) In the third step the received SPL data is correlated to a specific source-to-receiver geometry by determining the CPA of each ship and calculating the source-to-receiver range at the point. The received SPL data at CPA can then be corrected by the theoretical propagation loss for the known range at CPA, the known receiver depth, and the estimated source depth,[11] and resulting source spectra can be generated. Since several methods are available for determining CPA, this step is examined in some detail in Appendix F. Also, since the speed of advance of each ship is approximately known, the actual calculations are carried out 1 h after CPA to minimize the range sensitivity of the propagation loss curve.

(U) This refinement has the added advantage of utilizing the ARL:UT normal mode model in a source-to-receiver range where it shows very good agreement with a Navy standardized ray-trace transmission loss model (FACT)[8] and a parabolic equation transmission loss model (P.E.),[9] both of which are described along with the ARL:UT normal mode model in Appendix E.

B. Error Analysis

(U) This section has examined a method which was used to make a preliminary estimate of source sound pressure levels from the four events included in the appendices. Since there are several possible sources of error in this method, an error analysis is included here to serve as a basis for comparing these results with results from previous source level studies.

(U) The possible significant errors may be enumerated as (1) measurement errors in raw data and data reduction, (2) range errors in calculating transmission loss, and (3) errors in calculated transmission loss.

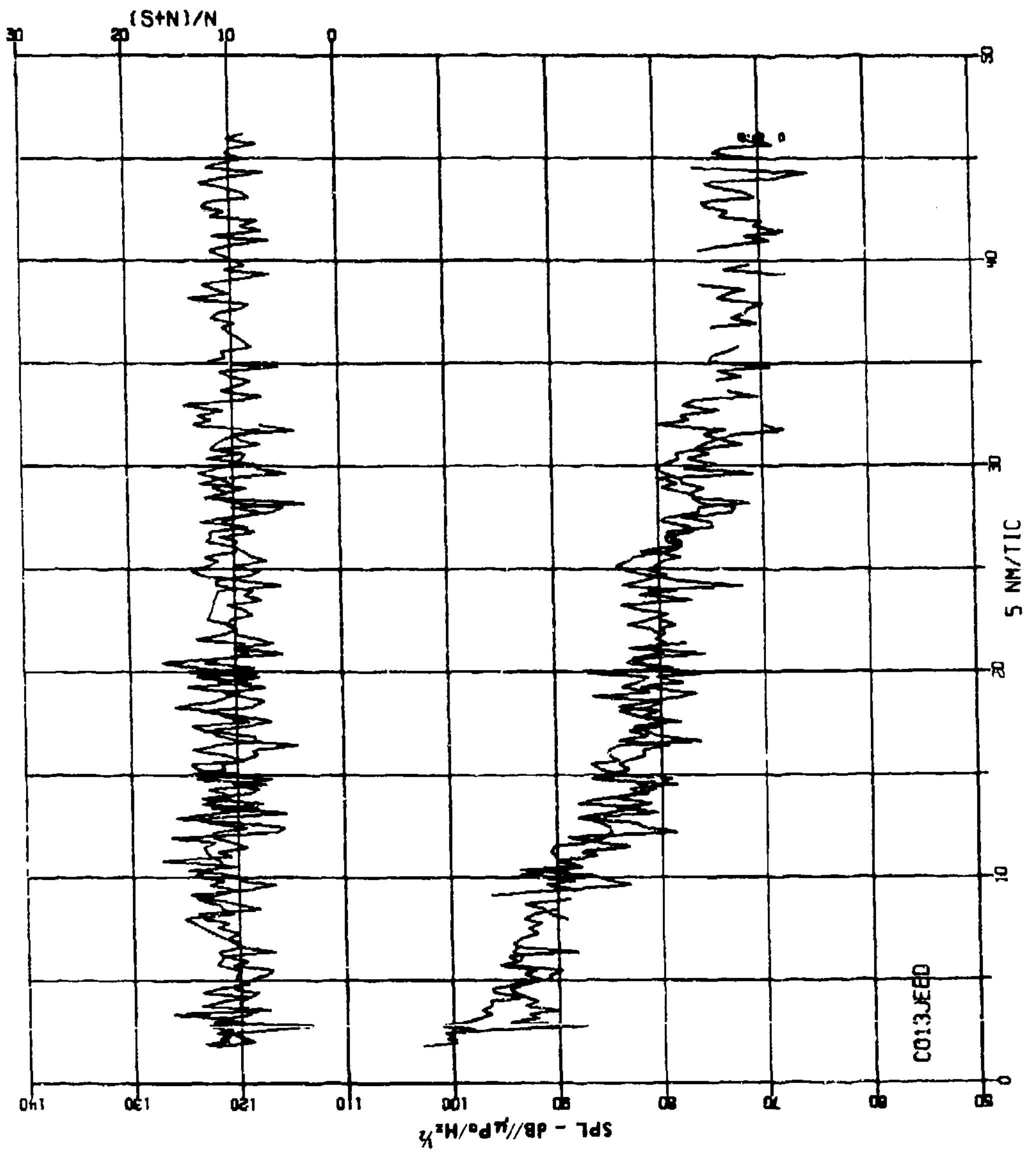

FIGURE 4
SUPERIMPOSED PROPAGATION LOSS AS A FUNCTION OF RANGE AT 25.0 Hz FOR A SOURCE DEPTH OF 6.0 m, RECEIVER DEPTH OF 4853.0 m, AND A PACIFIC SILT BOTTOM ONTO RECEIVED SPL AS A FUNCTION OF RANGE AT 26.6 Hz FOR A 4853.0 m HYDROPHONE SHOWING JEEO AT CPA (U)

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(U) The measurement errors associated with the raw data and the data processing, including the graphical outputs, have been kept to a minimum through use of extensive calibration procedures throughout the process. These procedures will not be examined in this document; however, an estimate of ±1 dB can be assigned as measurement error for the reduced CHURCH OPAL data.

(C) The second possible significant error occurs in calculating range from source to receiver. The primary limitation here is the accuracy with which the ship tracks can be reconstructed. The ship's reports supplied by FNWC include only 0.1° resolution or a resolution of about 6 nm on the earth's surface. The effect of this error in calculating transmission loss has been minimized by utilizing the propagation loss curve in a region where it shows minimum range sensitivity, at medium ranges (greater than 10 nm). The minimum range associated with CPA ±1 h for the four subject events is 16 nm. An error of 6 nm in this region will result in only a 3 dB transmission loss error (from Fig. 4).

(U) The third possible error results from the uncertainty in calculating a precise propagation loss curve. Although extensive analysis including the careful use of a normal mode propagation loss model has been used in an attempt to minimize this error. Propagation loss uncertainty may yet be the largest single error contributor. Uncertainties in subbottom composition, source depths, etc., have made the selection of normal mode parameters difficult. At present the extremes of the error may be estimated from Table E-I in Appendix E. At 30 nm the FACT subbottom type 1 (perfect reflector bottom) model yields a propagation loss of 95 dB, whereas the FACT subbottom type 3 (perfect absorber bottom) yields a propagation loss of 111 dB. At 30 nm the loss predicted by the ARL:UT normal mode model is 103 dB or ±8 dB of the extremes of FACT. Since the bottom is presumably neither a perfect reflector nor a perfect absorber, the normal mode prediction is very reasonably midway between the two FACT models. Source depth sensitivity will require additional future study but may be nominally set at approximately 1 dB/m of error

(U) based on many normal mode runs at differing source depths. Thus, for the purpose of this document, a propagation loss curve error of ±6 dB due to bottom parameter error and ±2 dB due to source depth and other errors at ranges of 30 nm is not unreasonable. The total error due to propagation loss curves could then be as much as ±8 dB, although it is probably much less.

(U) In conclusion, the three significant errors in the estimation of source levels are (1) measurement, ±1 dB, (2) range, ±3 dB, and (3) transmission loss, ±8 dB.

IV. SOURCE LEVEL RESULTS

A. Source Spectrum Level Plots

Results of source spectrum level calculations are presented in Figs. 5 through 8 for the four merchant vessels discussed in this paper. The pertinent data related to each event are summarized in Table II.

B. Comparison with Previous Results

(U) The source spectrum level plots may be most readily compared with the results obtained by Wittenborn. Since both this report and the Wittenborn document adjusted the entire spectrum by a constant value, it is fair to say that any differences between the two are primarily the result of differences in transmission loss estimations. The broadband level at 25 Hz in the Wittenborn report for JEEO appears near 160 dB//μPa/Hz$^{1/2}$. This appears to be in close agreement with Fig. 5 where the same line appears with a peak at approximately 163 dB//μPa/Hz$^{1/2}$. A similar analysis for events 3EVR and SDHT yields similar broadband levels at 25 Hz. For event PIRN, the ARL:UT results appear to be slightly lower, on the order of 4 dB. Thus, the maximum deviation between the Wittenborn document and this document for the four events analyzed is +3 dB and -4 dB, well within the error range of these calculations.

(C) As stated in the introduction to this document, the estimated source level of 25 Hz for all four events is on the order of 10 dB higher than the data presented by Ross and Alvarez.[2] The Ross and Alvarez data were presented for normalized ships 152 m (500 ft) in length and traveling at 15 kt. When the data presented in Figs. 5 through 8 are corrected by the normalization constants given by Ross and Alvarez, the range of deviation is from a low of +6 dB for event 3EVR to a high of +19 dB for event SDHT. However, the

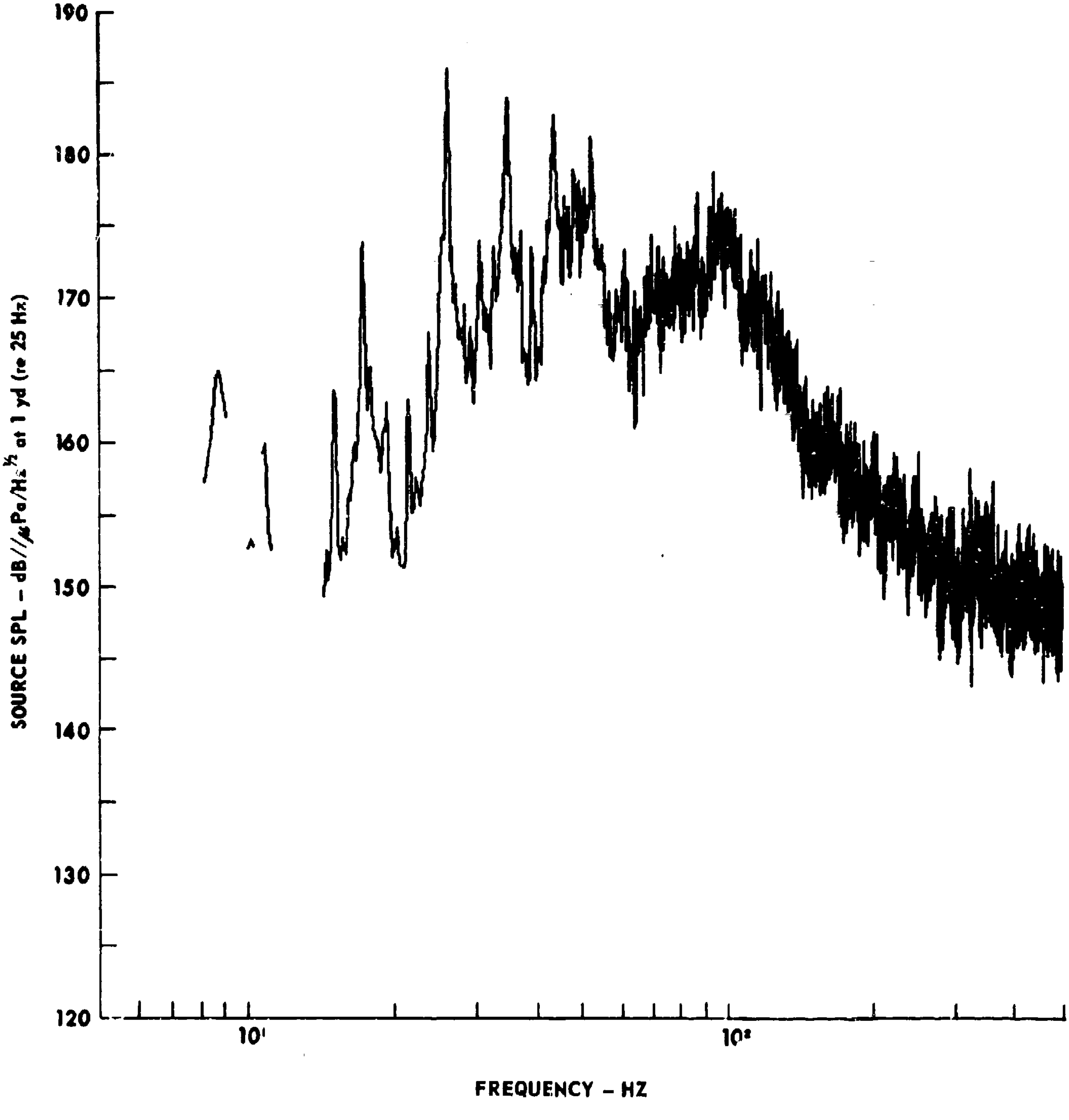

FIGURE 5
ESTIMATED (25 Hz) SOURCE SPL FOR EVENT JEEO (21)

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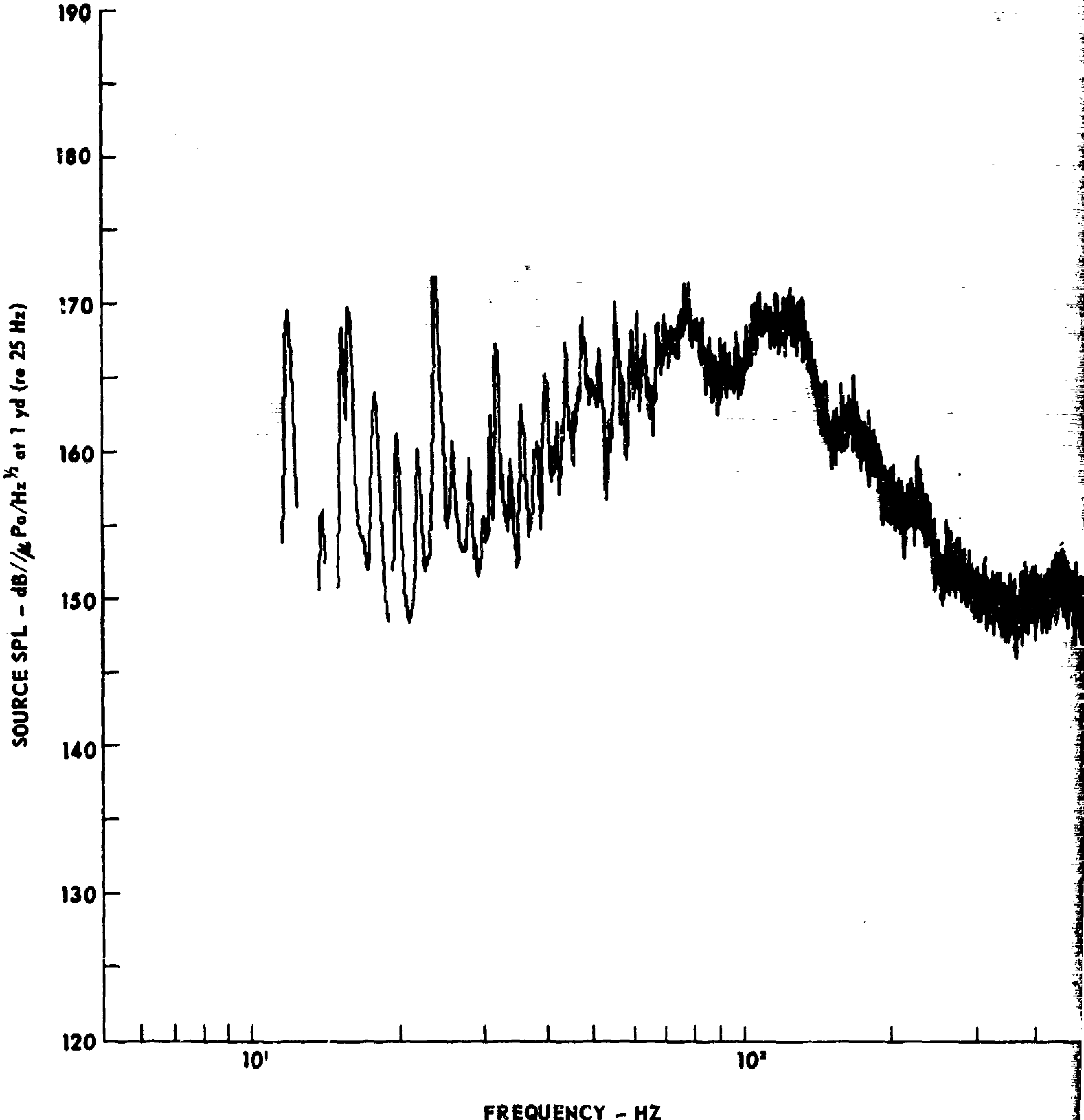

FIGURE 6
ESTIMATED (25 Hz) SOURCE SPL FOR EVENT 3EVR (U)

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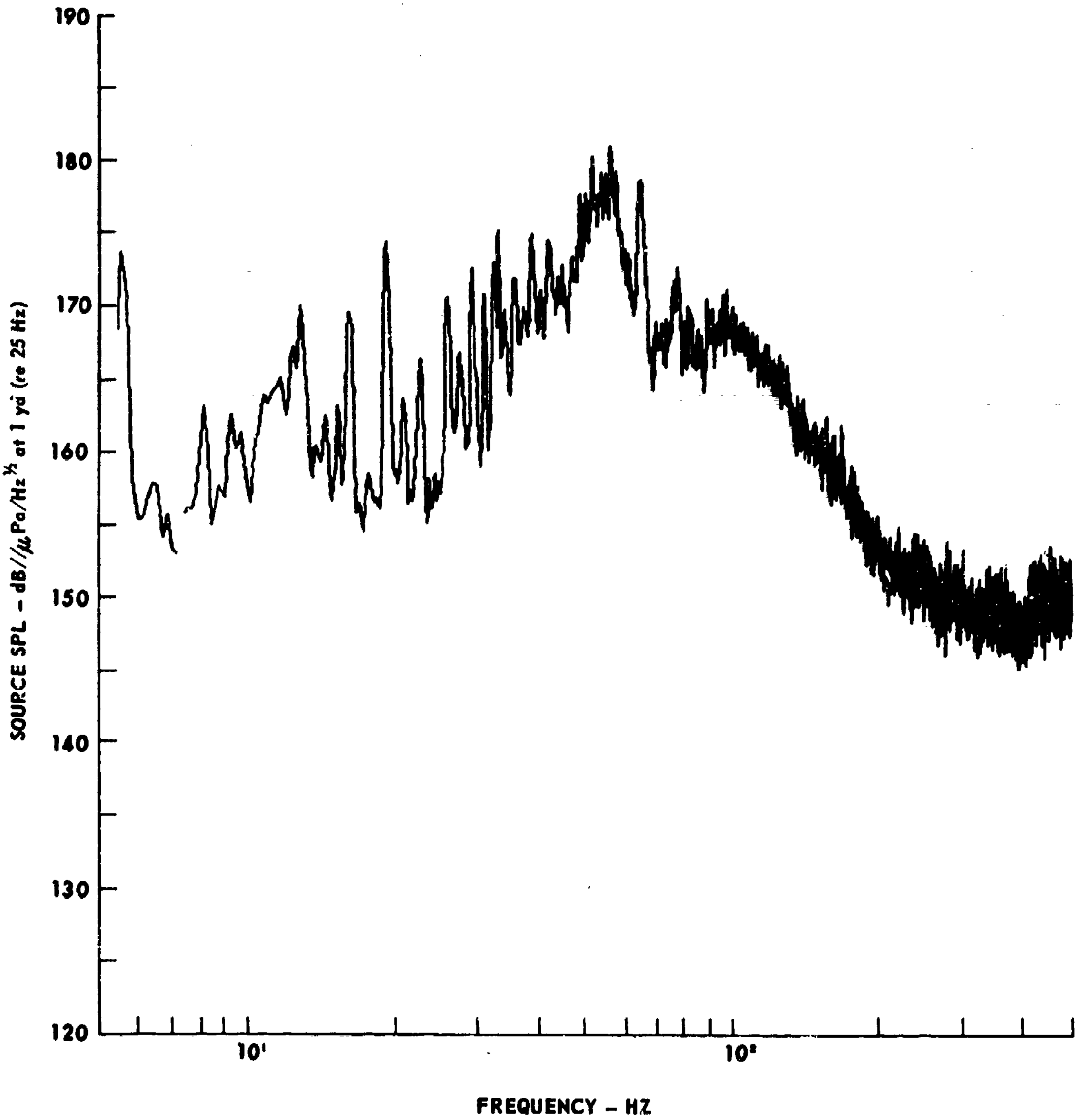

FIGURE 7
ESTIMATED (25 Hz) SOURCE SPL FOR EVENT PIRN (u)

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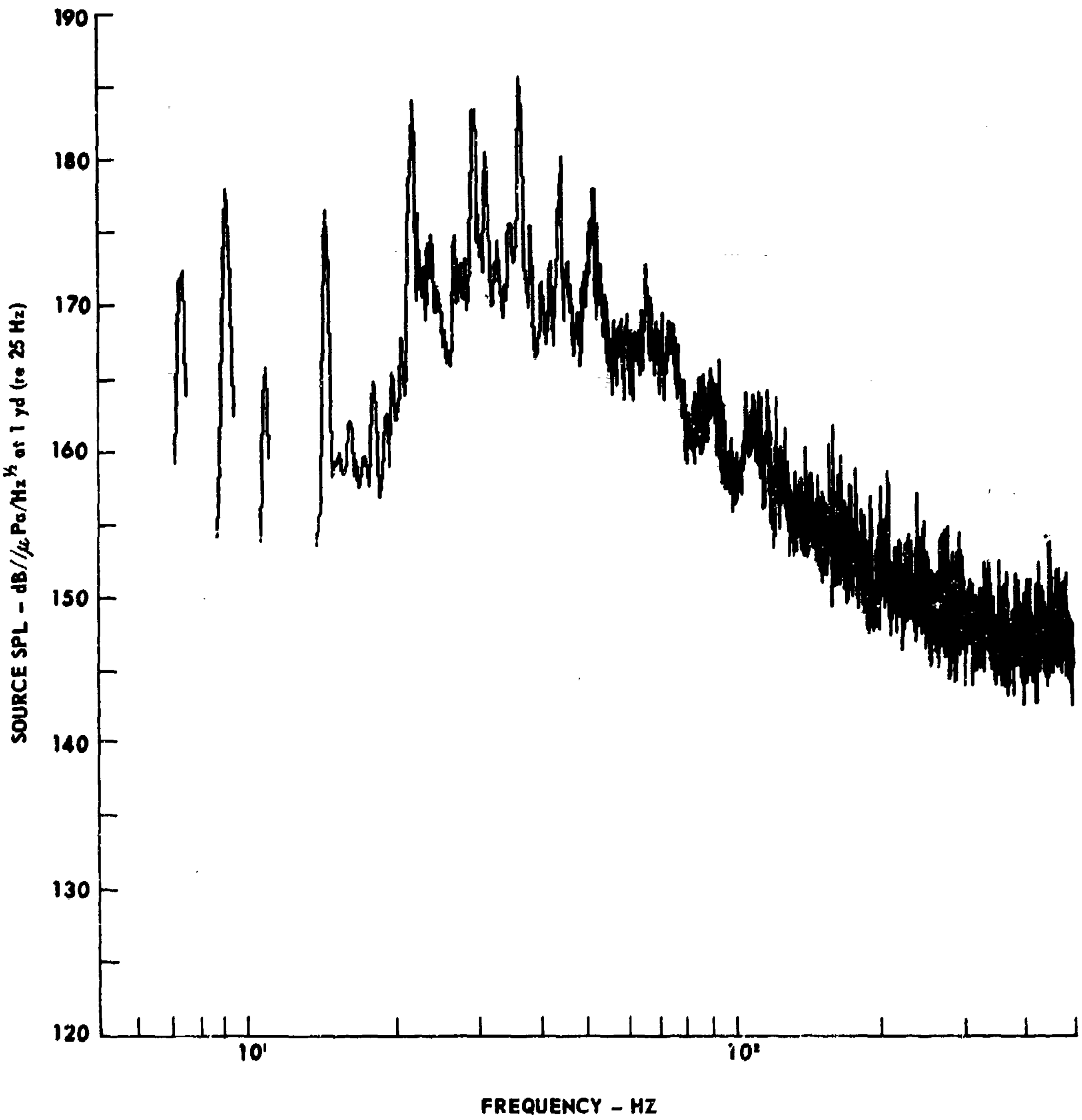

FIGURE 8
ESTIMATED (25 Hz) SOURCE SPL FOR EVENT SDHT (U)

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(C) TABLE II

SOURCE LEVEL DATA FOR A 25 Hz LINE (U)

SHIP	SOA	CPA RANGE	CPA ±1 h RANGE	PL CPA	PL CPA ±1 h	25 Hz SPL	Estimated 25 Hz Source SPL at 1 yd
	(kt)	(nm)	(nm)	(dB)	(dB)	(dB)	(dB//μPa/Hz$^{1/2}$)
JEEO	14.2	2	14	83	97	81	186
3EVR	15.6	7	17	91	99	66	173
PIRN	14.7	10	18	96	99	60	167
SDHT	18.3	14	19	85	100	77	185

(C) Ross and Alvarez data were collected in shallow water by using a semiempirical propagation loss at a single frequency. This could have the effect of biasing their data low at lower frequencies and may account for the rather large differences at 25 Hz between their data and the data presented here.

(C) Another comparison of these source level estimations can be made with more recent data presented in a NAVOCEANO[3] (1975) report. The authors of that report also applied the Ross and Alvarez normalization to three merchant vessels, the SUN PRINCE, the SCAPEWIND, and the CAP MATAGAN. All three ships were freighters traveling at similar speeds (9.8 to 14.6 kt) and were similar in length: 125 to 173 m (410 to 569 ft). From their data, the estimated source levels at 25 Hz appear to be slightly higher than those obtained by Ross and Alvarez, from +1 dB to +10 dB. This would place the NAVOCEANO results within approximately 5 dB of the results obtained here.

(C) The conclusions from these observations is that all the recent reports which estimated source spectrum levels have shown that the Ross and Alvarez estimations of 1964 were low on the order of 10 dB. ARL:UT has additional evidence that, in some cases, this figure could be as much as 20 dB for event SDHT presented in the appendices.

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APPENDIX A

JEEO (KANESHIZU MARU)

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1. <u>Ship Description</u>

Name: KANESHIZU MARU

Call Sign: JEEO

Type: Bulk Carrier (14.75 kt)

Owner: Chuo Shintaku Ginko K.K.

Builder: Kanasashi Zosensho (1971)

Dimensions: Length - 155.10 m (509 ft)
Breadth - 22.86 m (75 ft)
Draught - 9.23 m (30 ft)

Displacement: 12272 tons gross, 7091 tons net, 18254 tons summer dead weight

Machinery: Oil, 2-stroke, single acting 7-cylinder main propulsion (9400 bhp) 3 each: 300 kW, 445 Vac generators

2. <u>Measurement Data</u>

Time of CPA: 253/1300 (day/h)

Range at CPA: 2 nm

Speed of Advance: 14.2 kt

Wind Speed (at CPA): 8 kt

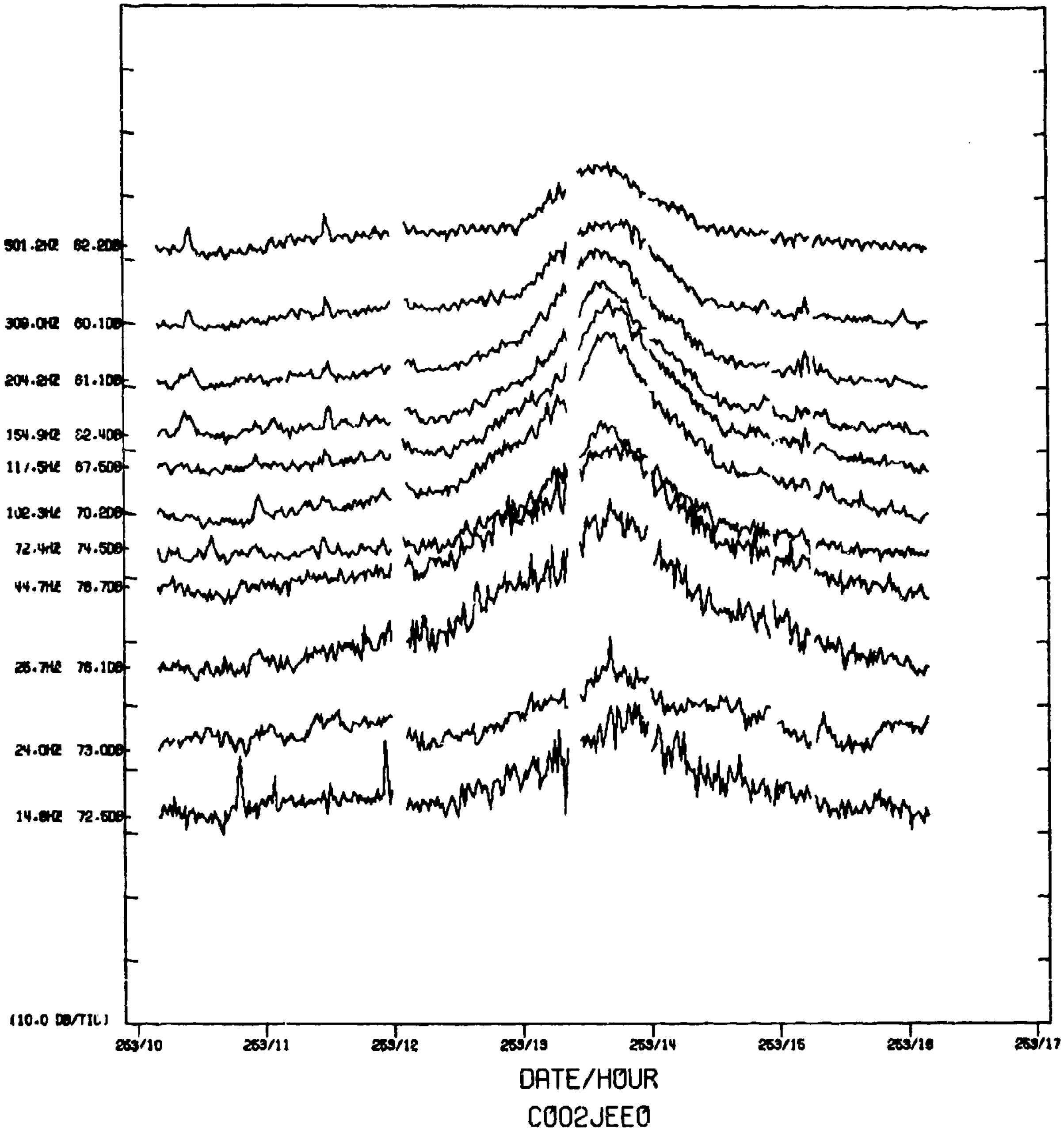

FIGURE A-1
JEEO TIME SERIES HYDROPHONE 02 (3459 m) (U)

ARL - UT
AS-77-352-P
KRP - DR
4 - 26 - 77

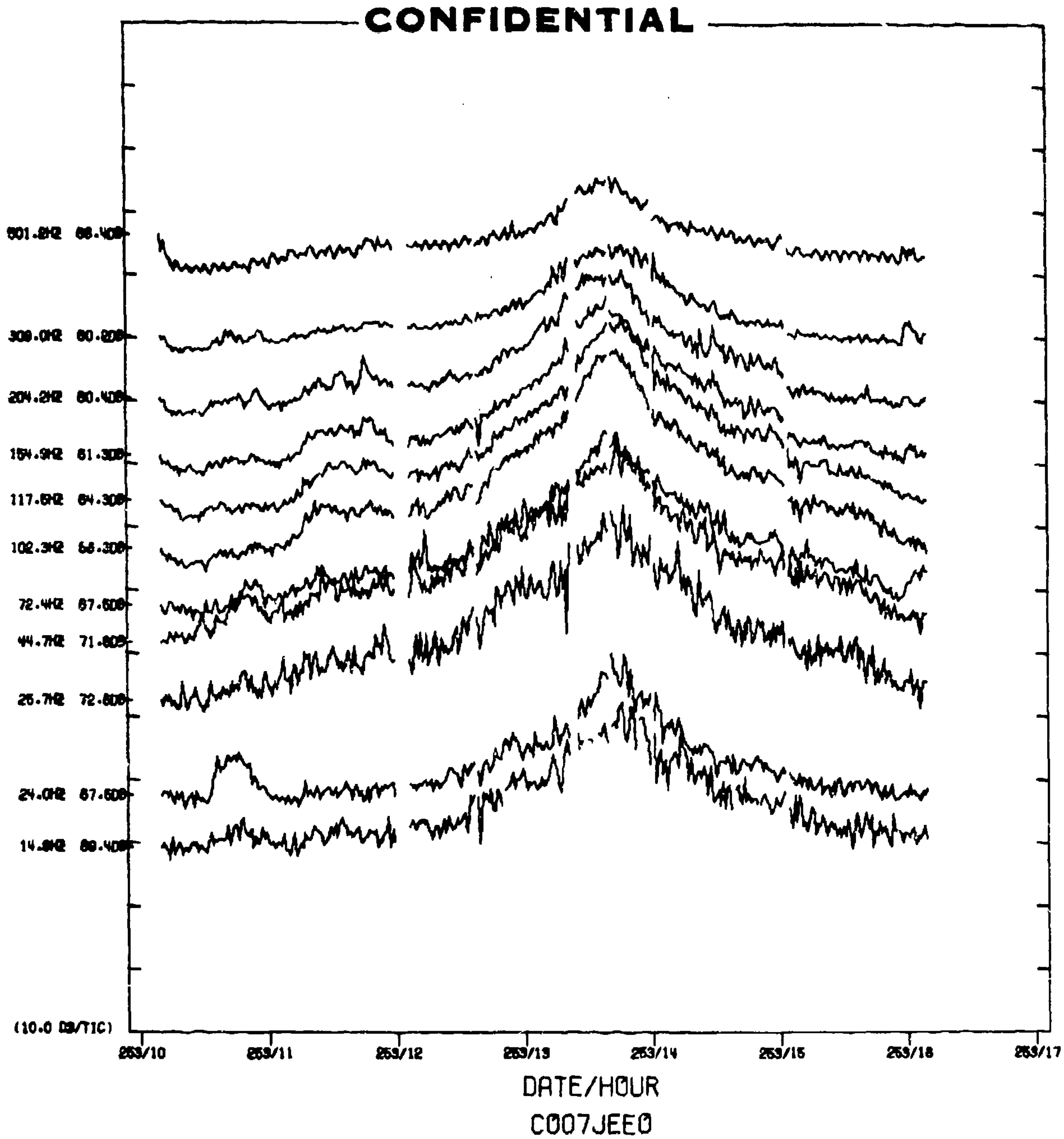

FIGURE A-2
JEEO TIME SERIES HYDROPHONE 07 (4459 m) (U)

ARL - UT
AS-77-353-P
KRP - DR
4 - 26 - 77

CONFIDENTIAL

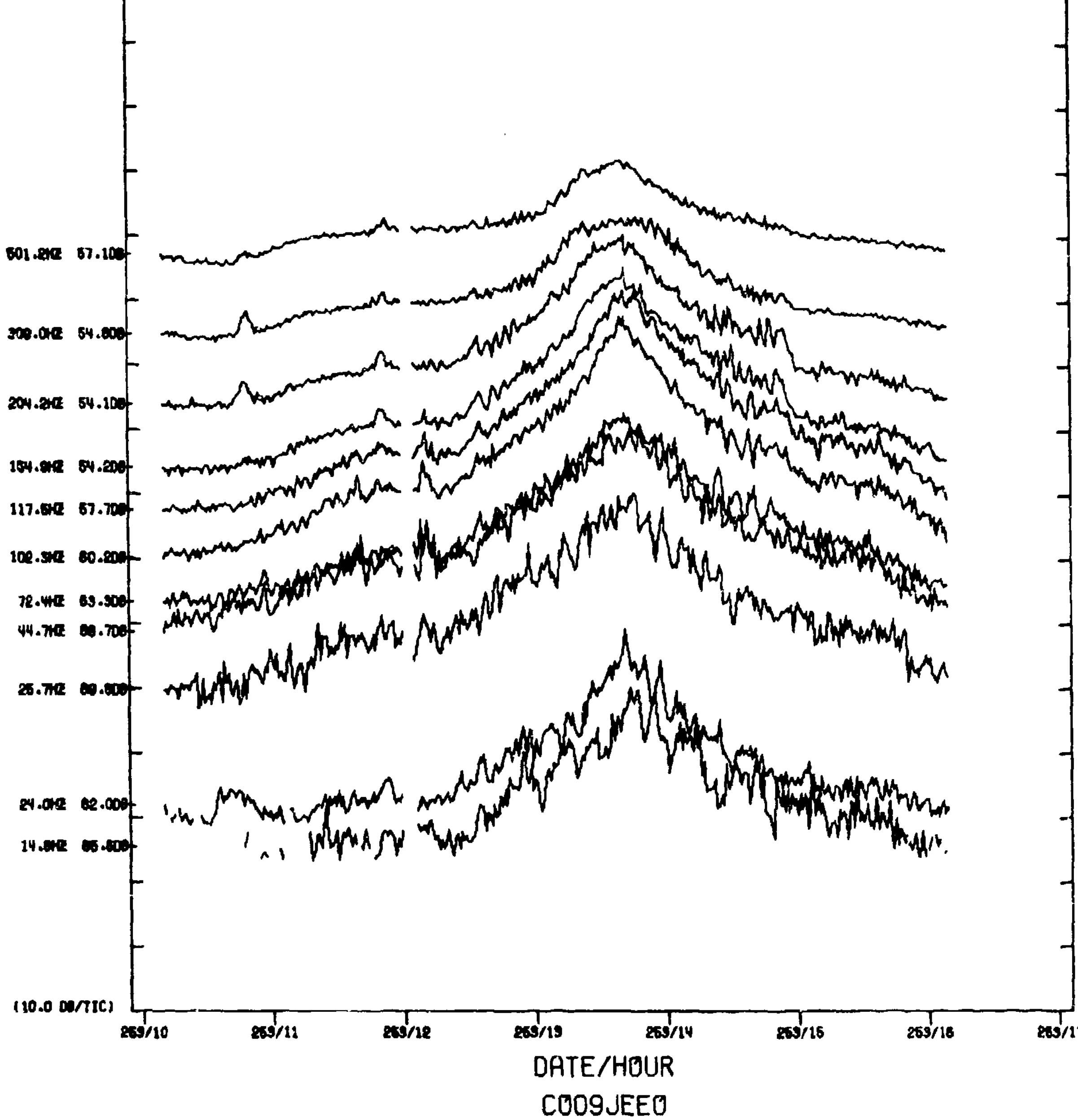

FIGURE A-3
JEEO TIME SERIES HYDROPHONE 09 (4681 m) (U)

ARL - UT
AS-77-354-P
KRP - DR
4-26-77

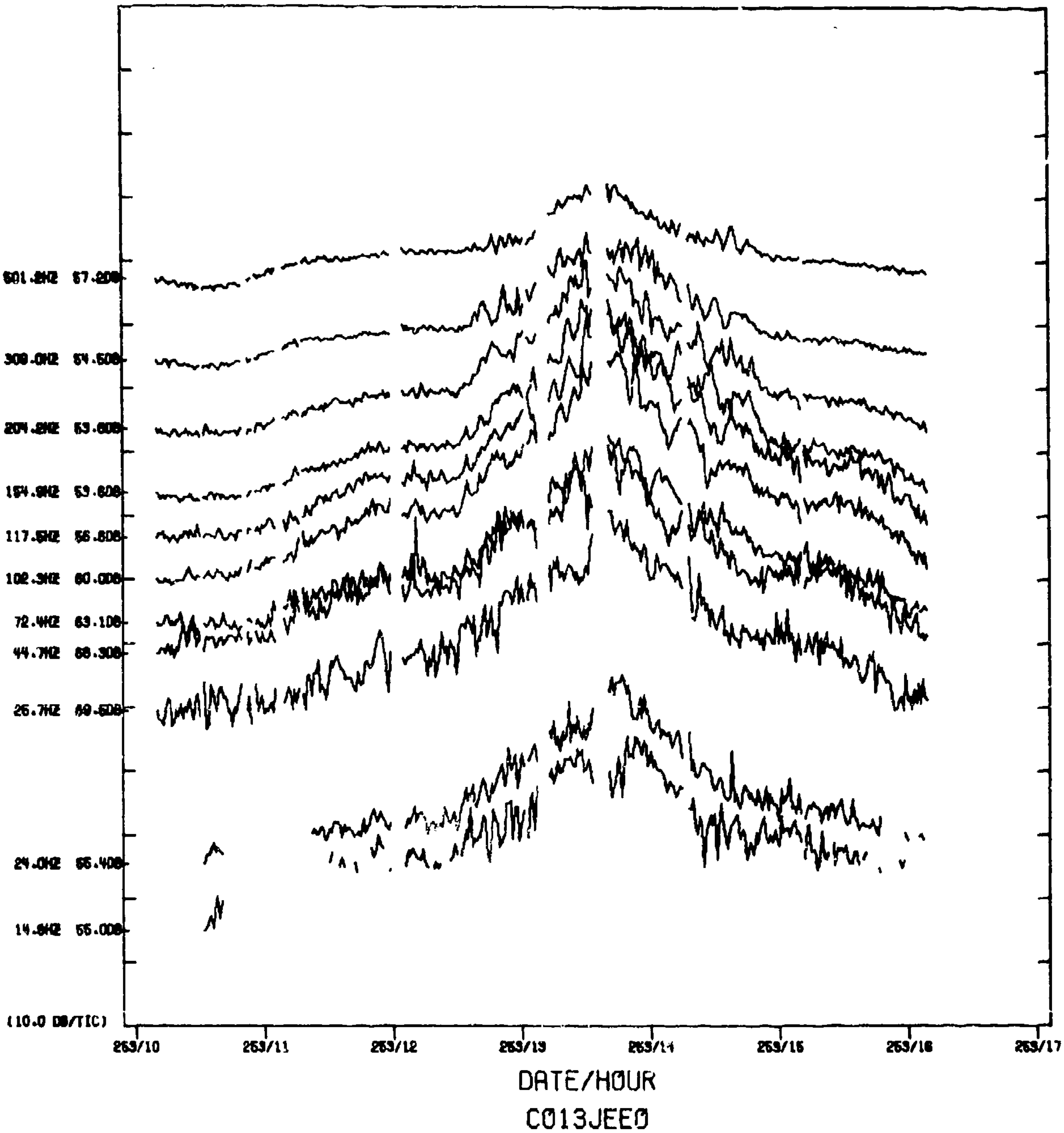

FIGURE A-4
JEEO TIME SERIES HYDROPHONE 13 (4853 m) (U)

ARL - UT
AS-77-355-P
KRP - DR
4-26-77

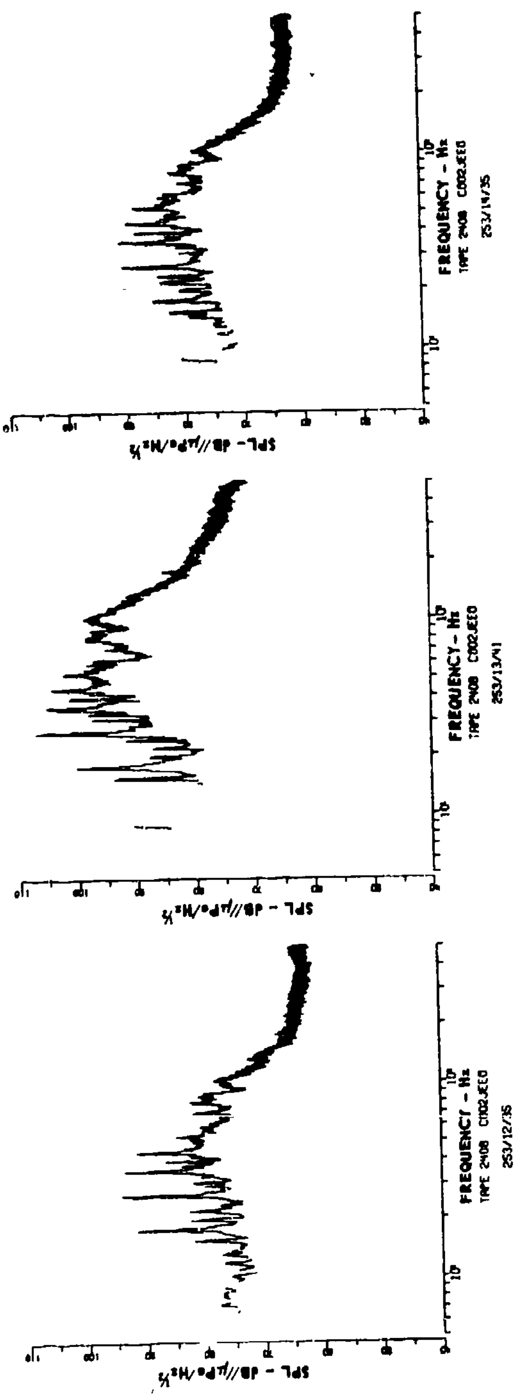

FIGURE A-5
JEEO SIGNATURES FOR HYDROPHONE 02 (U)

ARL - UT
AS-77-392
KRP - DR
5 - 3 - 77

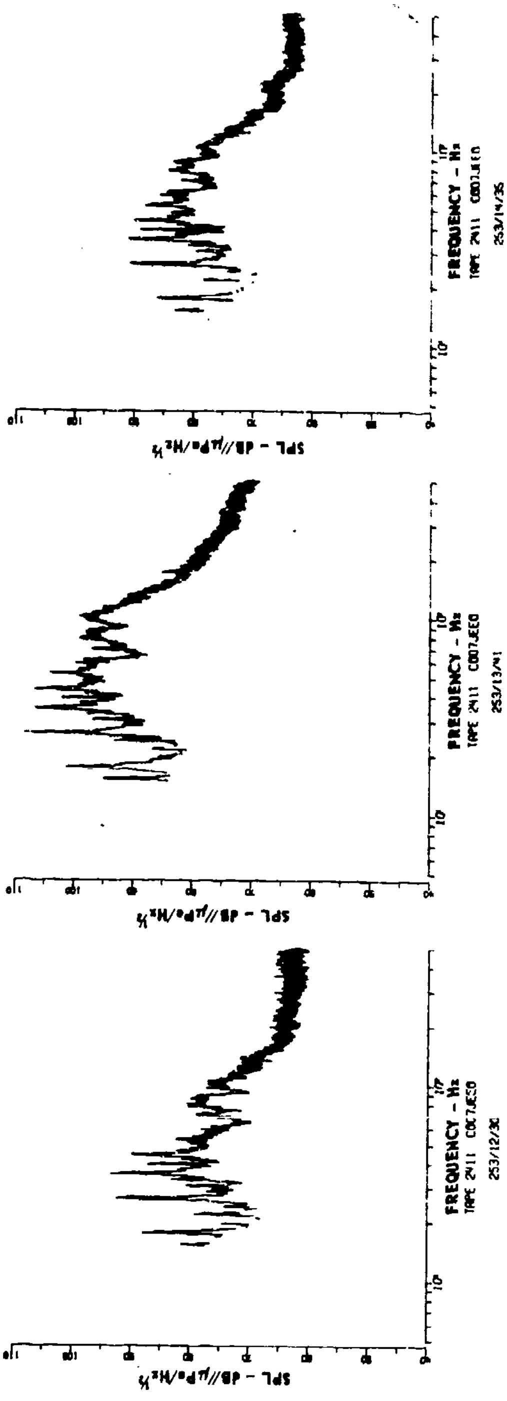

FIGURE A-6
JEEO SIGNATURES FOR HYDROPHONE 07 (U)

ARL - UT
AS-77-393
KRP - DR
5 - 3 - 77

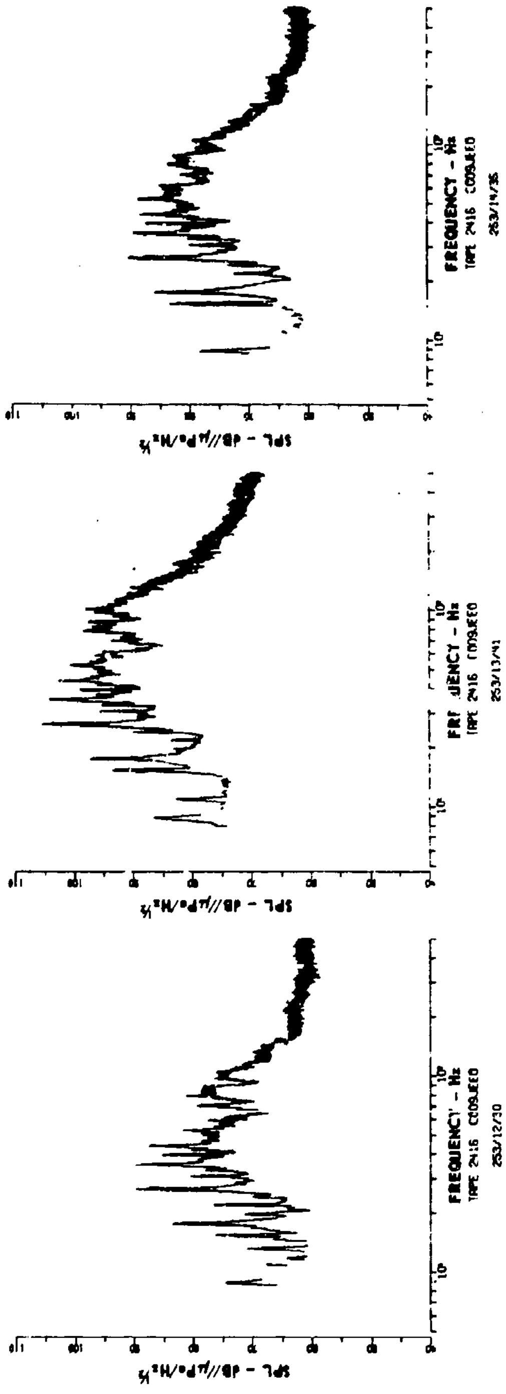

FIGURE A-7
JEEO SIGNATURES FOR HYDROPHONE 09 (U)

ARL - UT
AS-77-394
KRP - DR
5 - 3 - 77

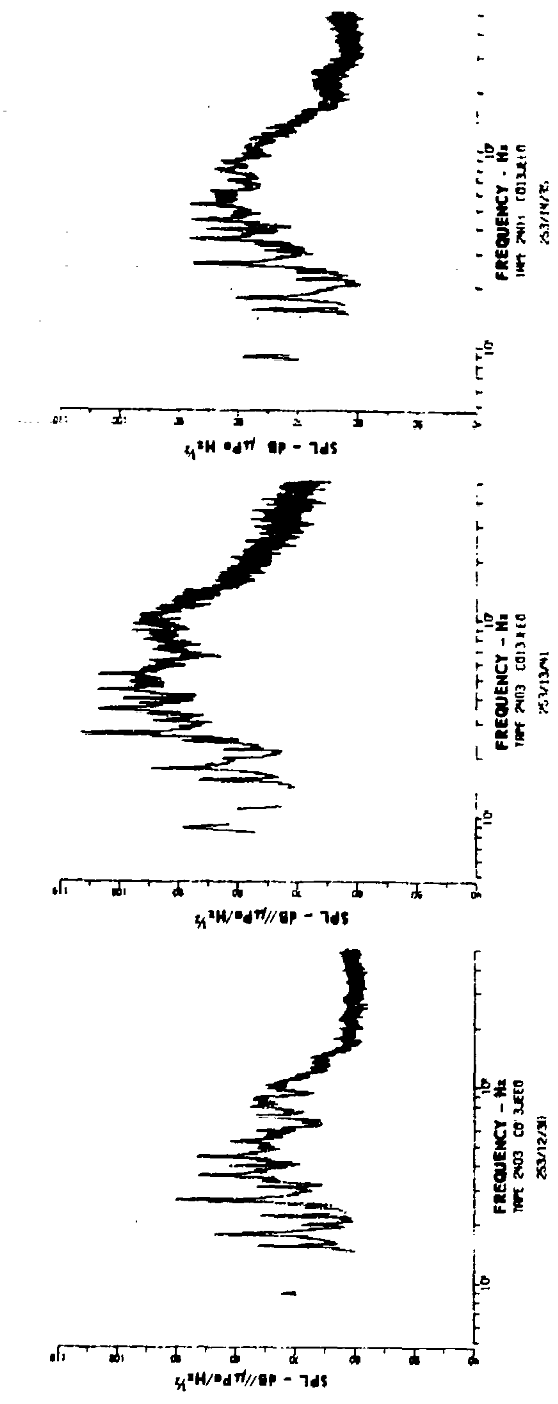

FIGURE A-8
JEEO SIGNATURES FOR HYDROPHONE 13 (U)

ARL - UT
AS-77-395
KRP - DR
5 - 3 - 77

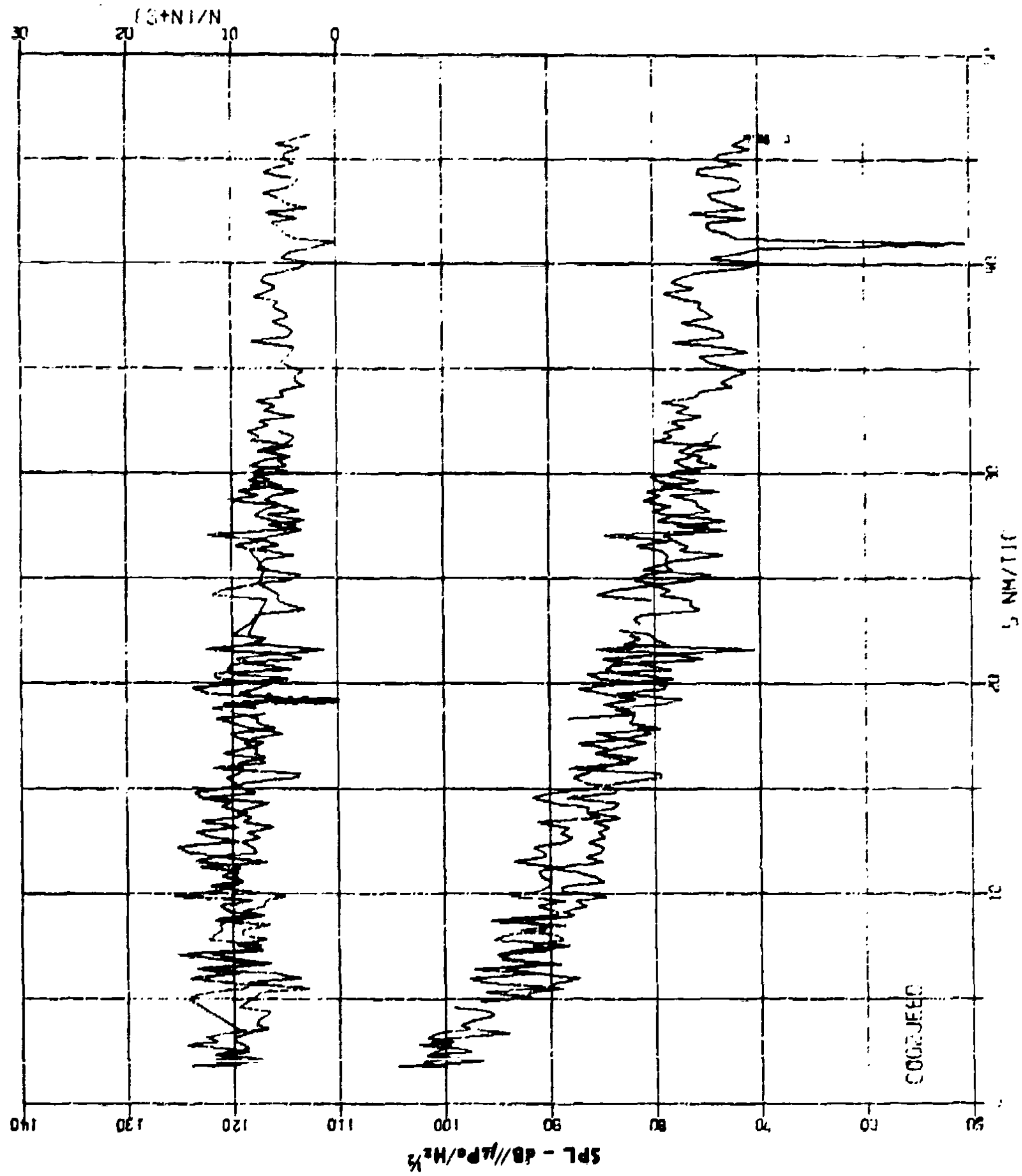

FIGURE A-9
RECEIVED SPL AS A FUNCTION OF RANGE
JEEO HYDROPHONE 02 (U)

ARL - UT
AS-77-406
KKP - DR
5 - 3 - 77

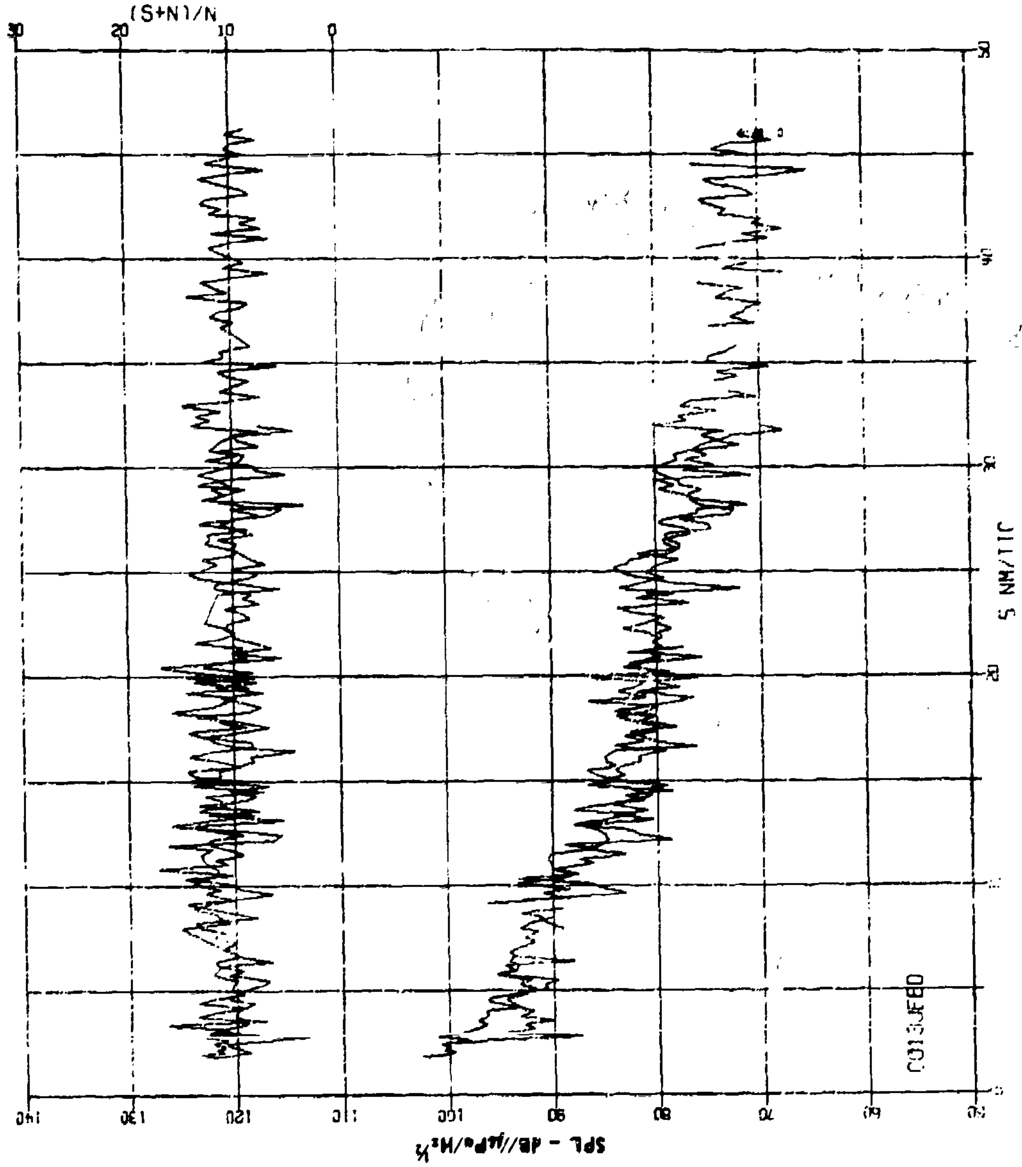

FIGURE A-10
RECEIVED SPL AS A FUNCTION OF RANGE
JEEO HYDROPHONE 13 (U)

ARL - UT
AS-77-407
KRP - DR
5 - 3 - 77

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APPENDIX B

3EVR (GREAT SUCCESS)

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(U) 1. Ship Description

Name: GREAT SUCCESS, ex ASO MARU

Call Sign: 3EVR

Type: TM General Cargo (no speed data available)

Owner: Great Fortune Navigation Company S.A.

Builder: Nishi Nippon Jukogyo (1951)

Dimensions: Length - 150.98 m (495 ft)
Breadth - 19.05 m (62 ft)
Draught - 8.414 m (28 ft)

Displacement: 7522 tons gross; 4184 tons net; 9951 tons summer dead weight

Machinery: 2 each: Oil, 2-stroke, single acting 6-cylinder (8400 bhp)
3 each: 230 kW, 230 Vdc generators

(U) 2. Measurement Data

Time of CPA: 250/1100 (day/h)

Range at CPA: 7 nm

Speed of Advance: ≅15.6 kt

Wind Speed (at CPA): 13 kt

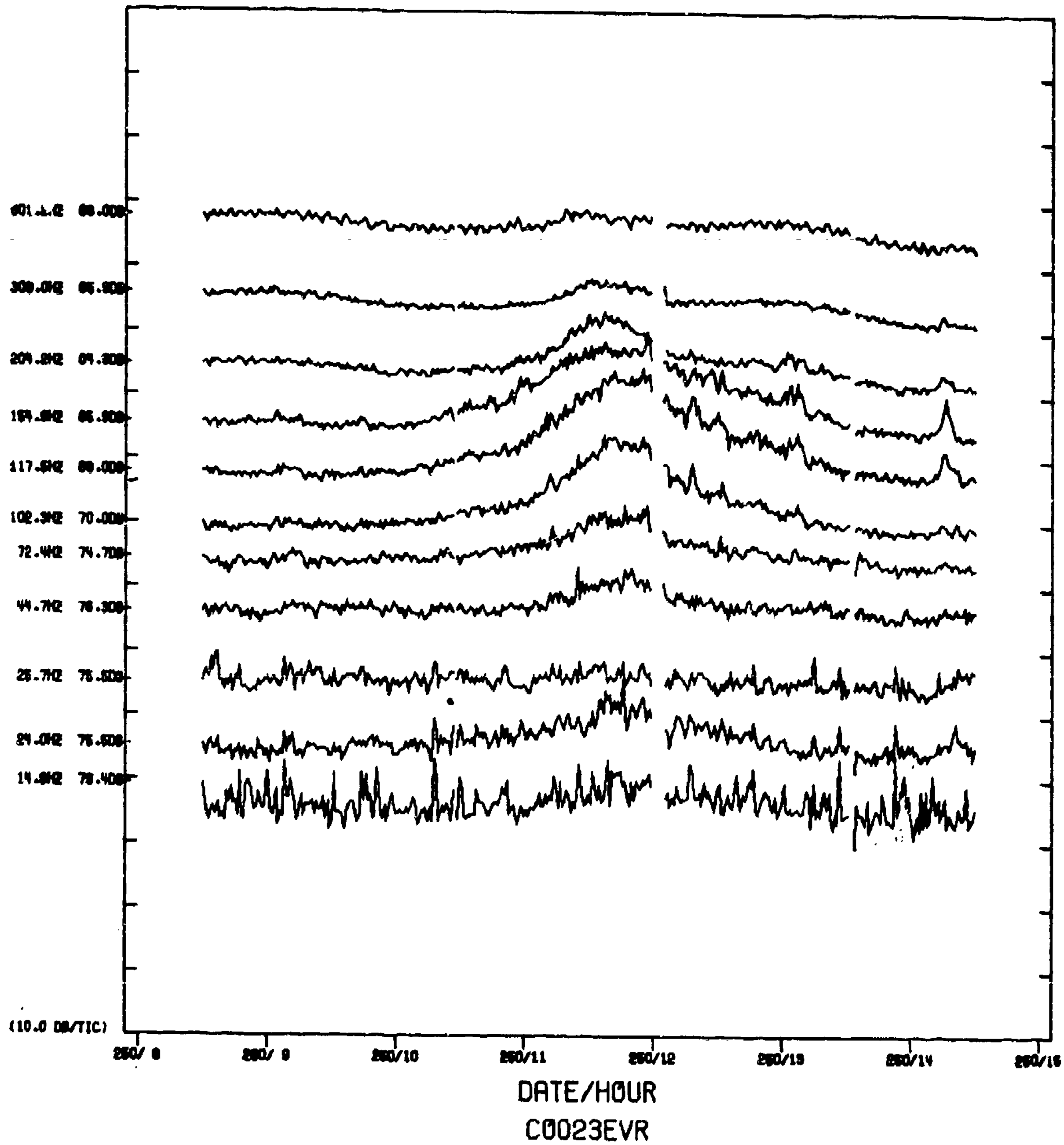

FIGURE B-1
3EVR TIME SERIES HYDROPHONE 02 (3459 m) (U)

ARL - UT
AS-77-356-P
KRP - DR
4 - 26 - 77

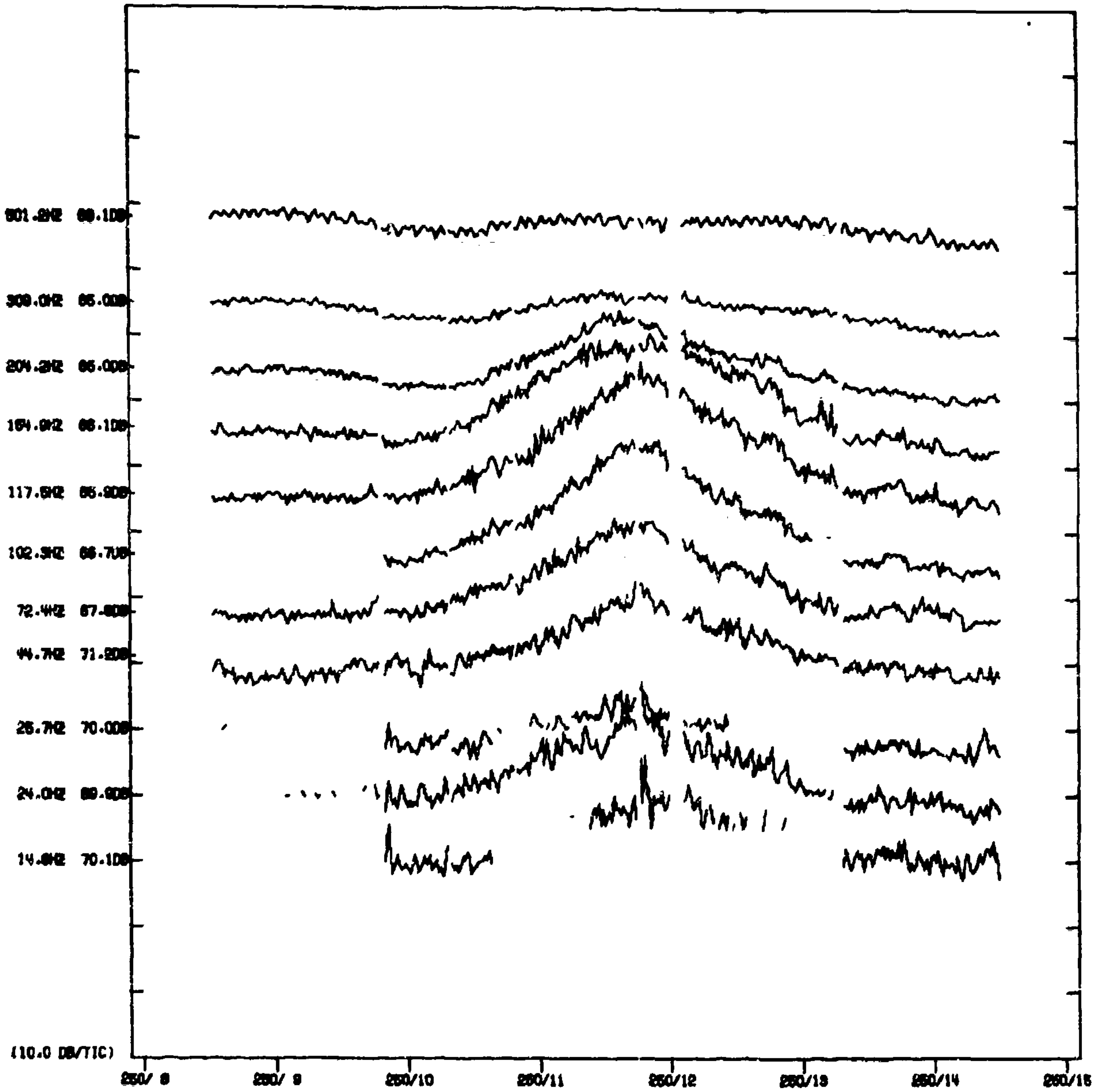

FIGURE B-2
3EVR TIME SERIES HYDROPHONE 07 (4459 m) (U)

ARL - UT
AS - 77 - 357 - P
KRP - DR
4 - 26 - 77

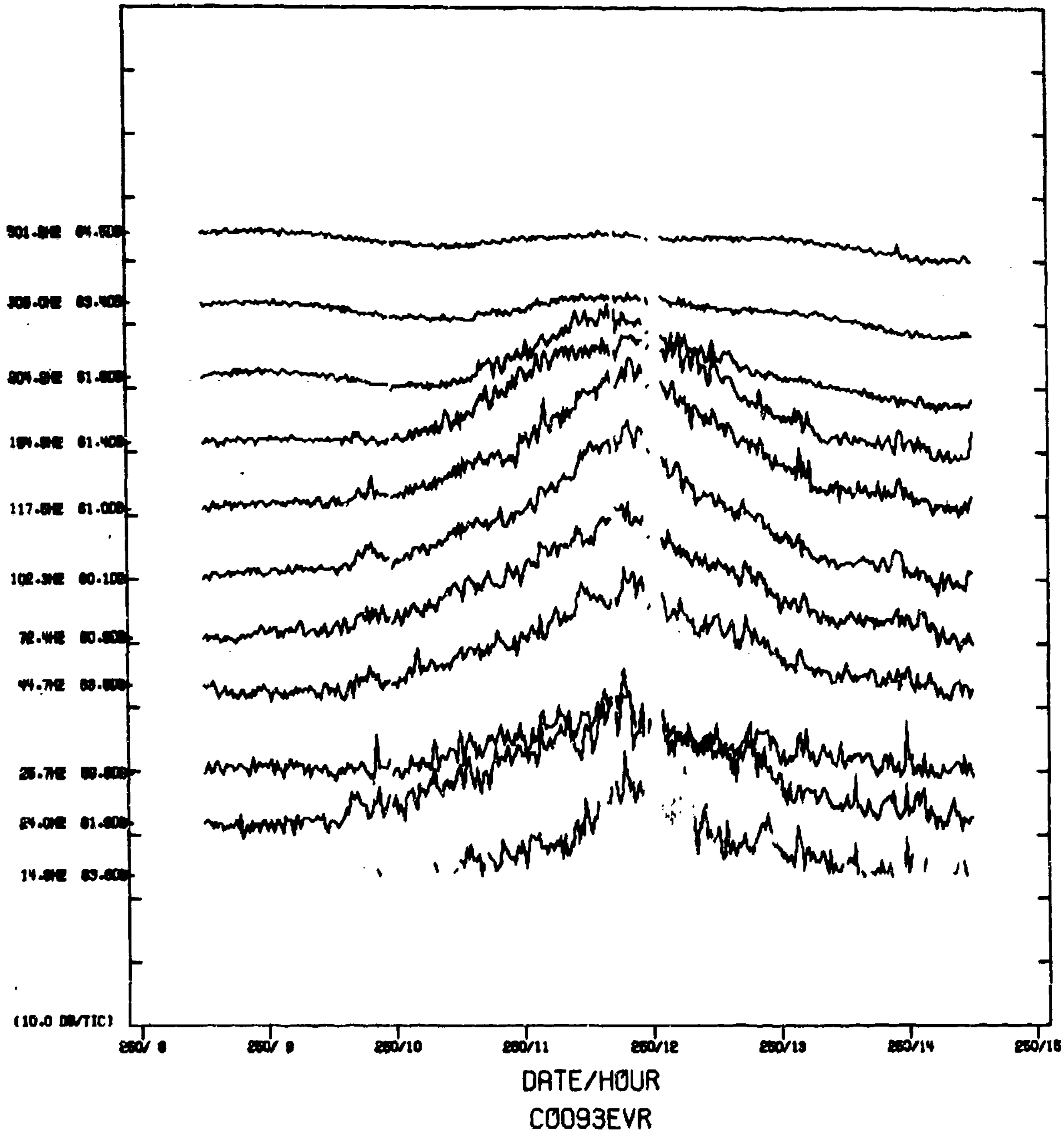

FIGURE B-3
3EVR TIME SERIES HYDROPHONE 09 (4681 m) (U)

ARL - UT
AS-77-358-P
KRP - DR
4-26-77

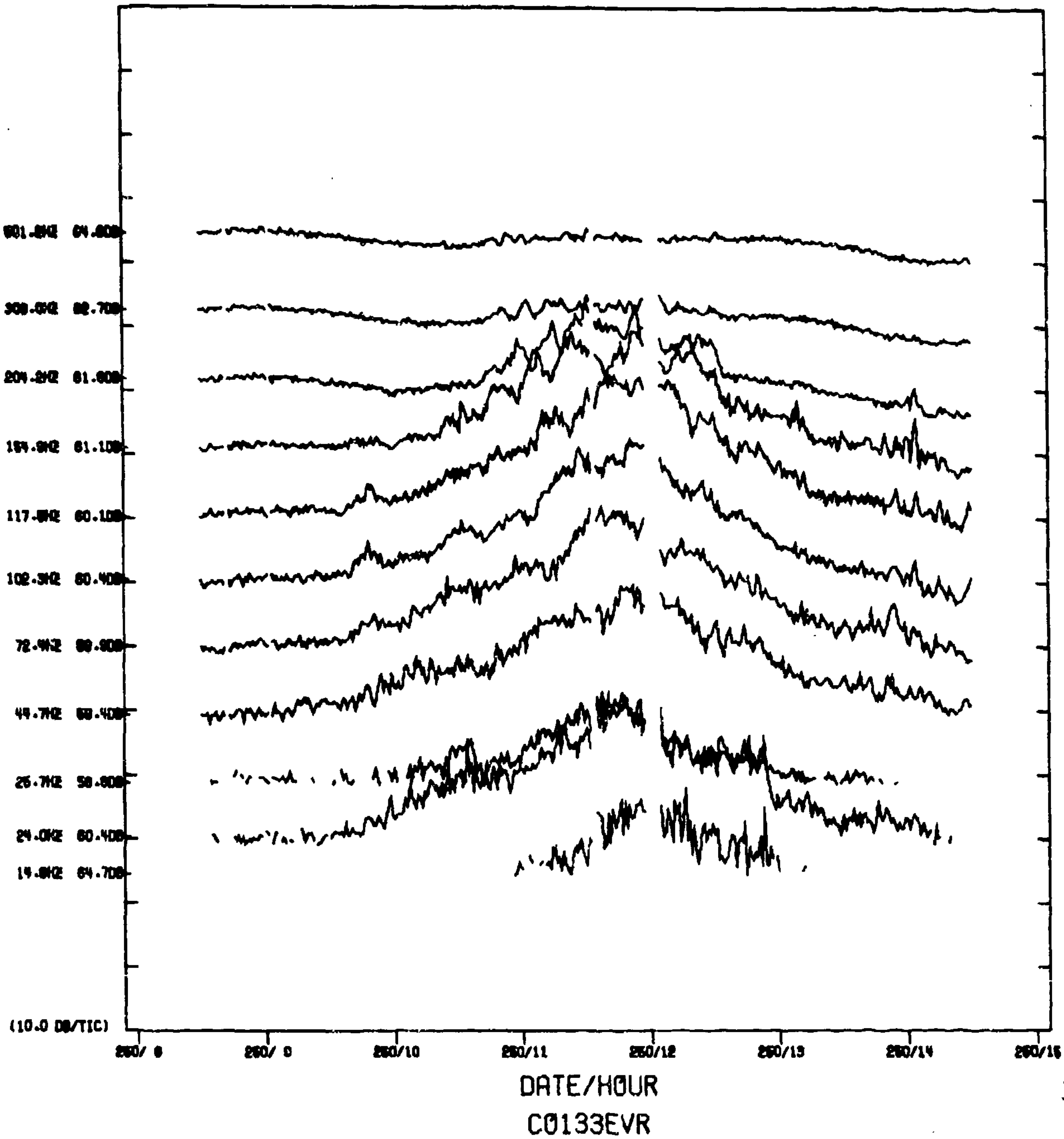

FIGURE B-4
3EVR TIME SERIES HYDROPHONE 13 (4853 m) (U)

ARL - UT
AS-77-359-P
KRP - DR
4 - 26 - 77

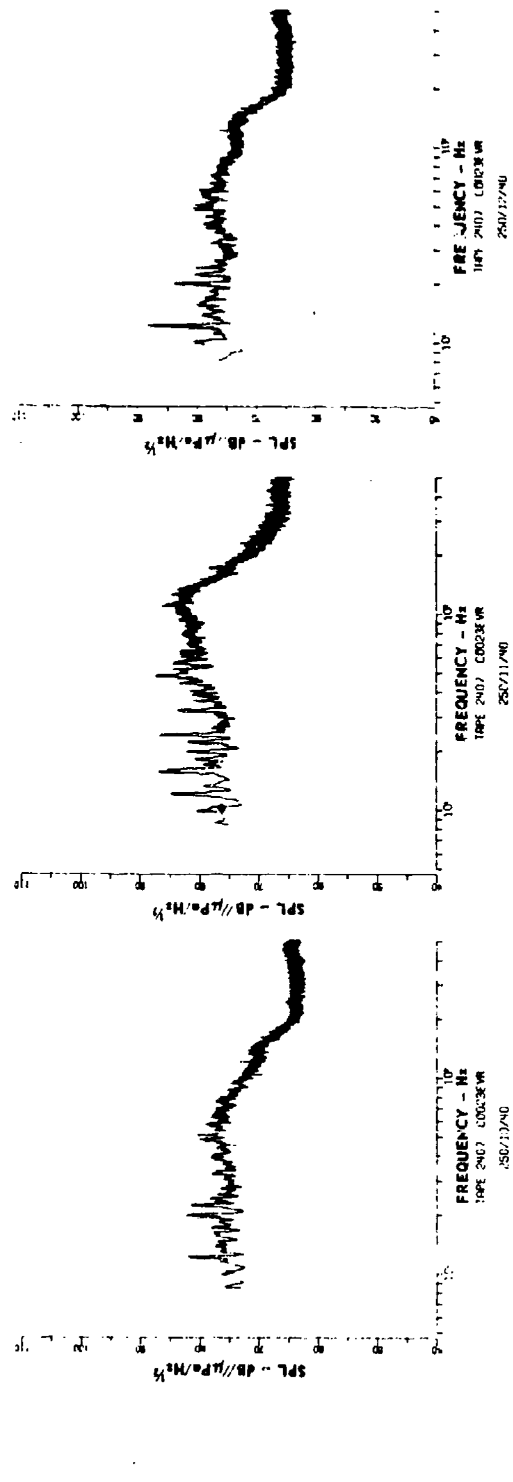

FIGURE B-5
3EVR SIGNATURES FOR HYDROPHONE 02 (U)

ARL - UT
AS-77-396
KRP - DR
5 - 3 - 77

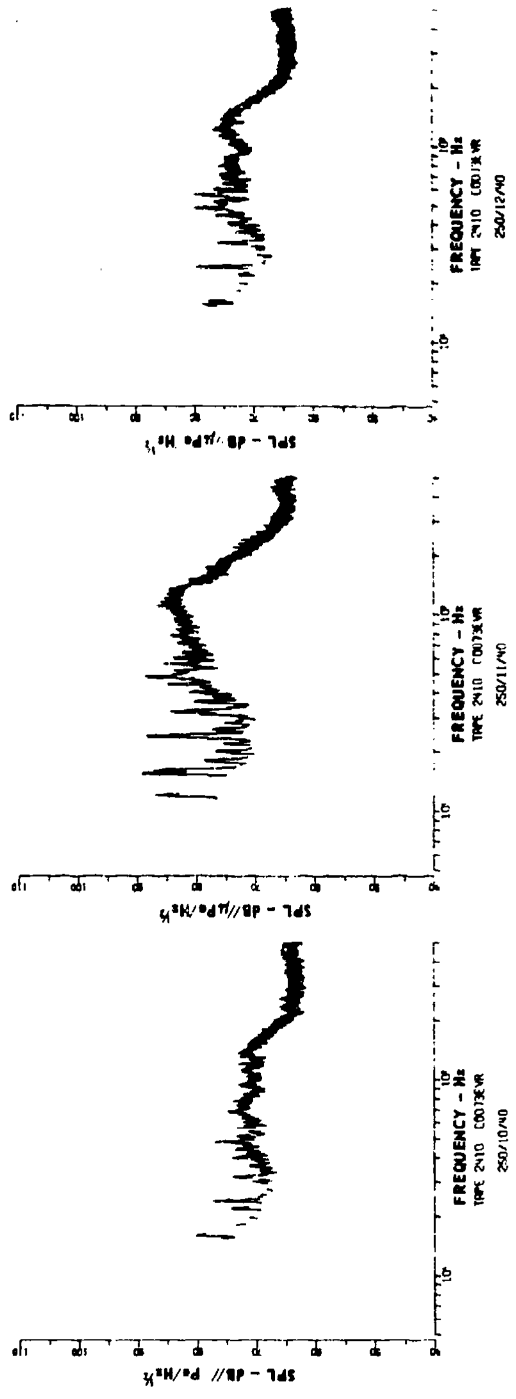

FIGURE B-6
3EVR SIGNATURES FOR HYDROPHONE 07 (U)

ARL - UT
BS-77-397
KRP - OR
5 - 3 - 77

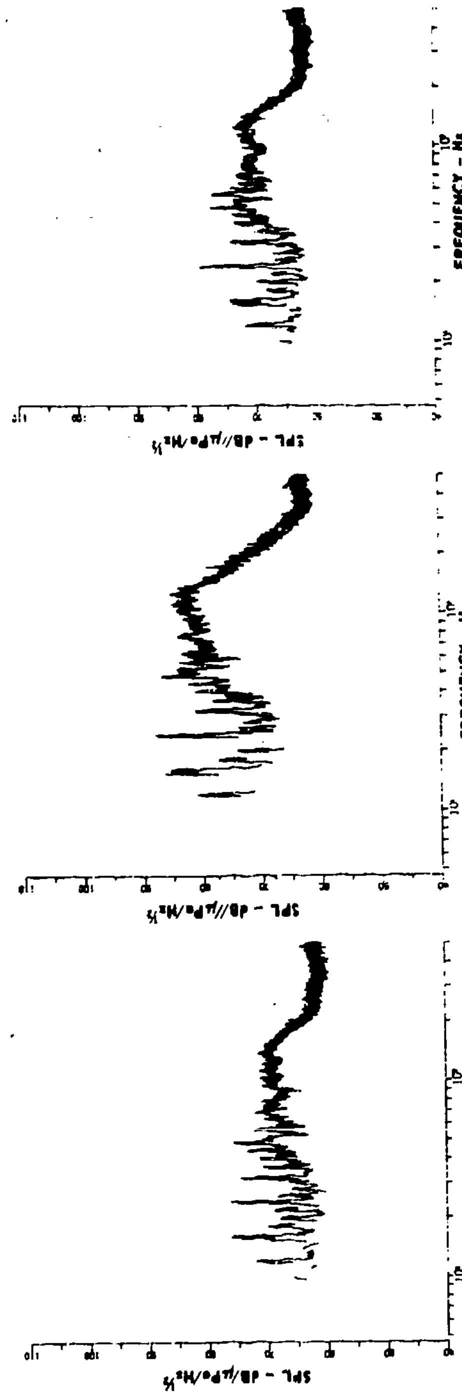

FIGURE B-7
3EVR SIGNATURES FOR HYDROPHONE 09 (U)

ARL - UT
AS-77-398
KRP - DR
5 - 3 - 77

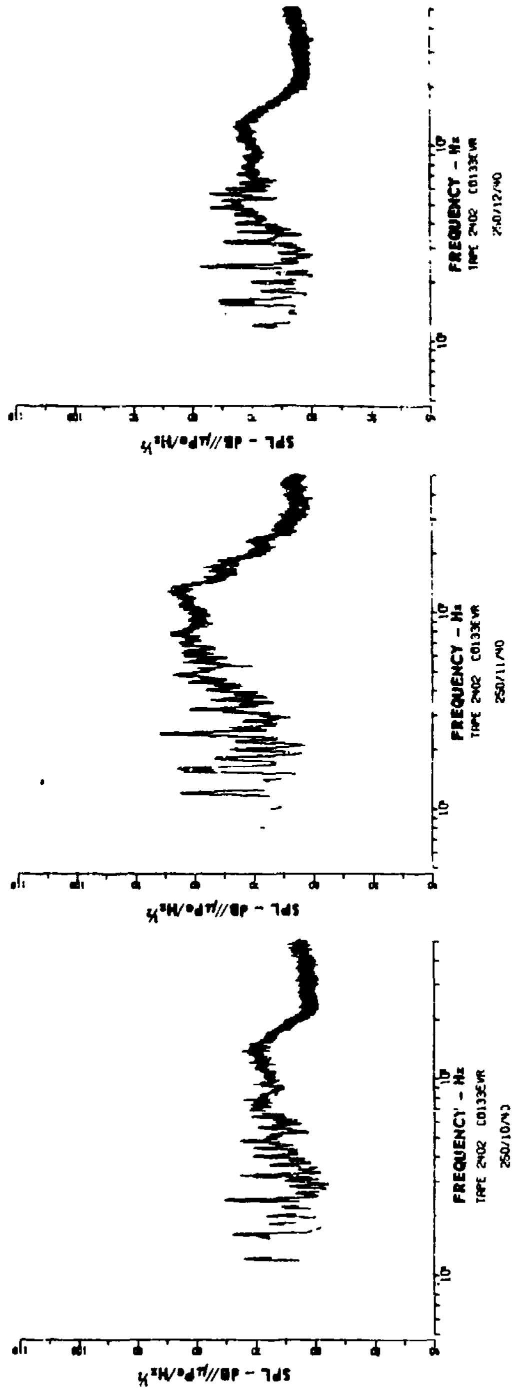

FIGURE B-8
3EVR SIGNATURES FOR HYDROPHONE 13 (U)

ARL:UT
AS.77.399
KRP - DR
5 - 3 - 77

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APPENDIX C

PIRN (WONORATO)

(U) 1. Ship Description

Name: WONORATO

Call Sign: PIRN

Type: General Cargo (16 kt)

Owner: Koninklijke Neolloyd B.V.

Builder: Howaldtswerke Ham. A.G.

Dimensions:	Length -	154.82 m (508 ft)
	Breadth -	20.15 m (66 ft)
	Draught -	8.25 m (27 ft)

Displacement: 7512 tons gross; 4181 tons net; 19882 tons summer dead weight

Machinery: Oil, 2-stroke, single acting 10-cylinder main propulsion (8250 bhp) 3 each: 200 kW, 200 Vdc generators

(U) 2. Measurement Data

Time of CPA: 257/1800 (day/h)

Range at CPA: 10 nm

Speed of Advance: ≅14.7 kt

Wind Speed (at CPA): 5 kt

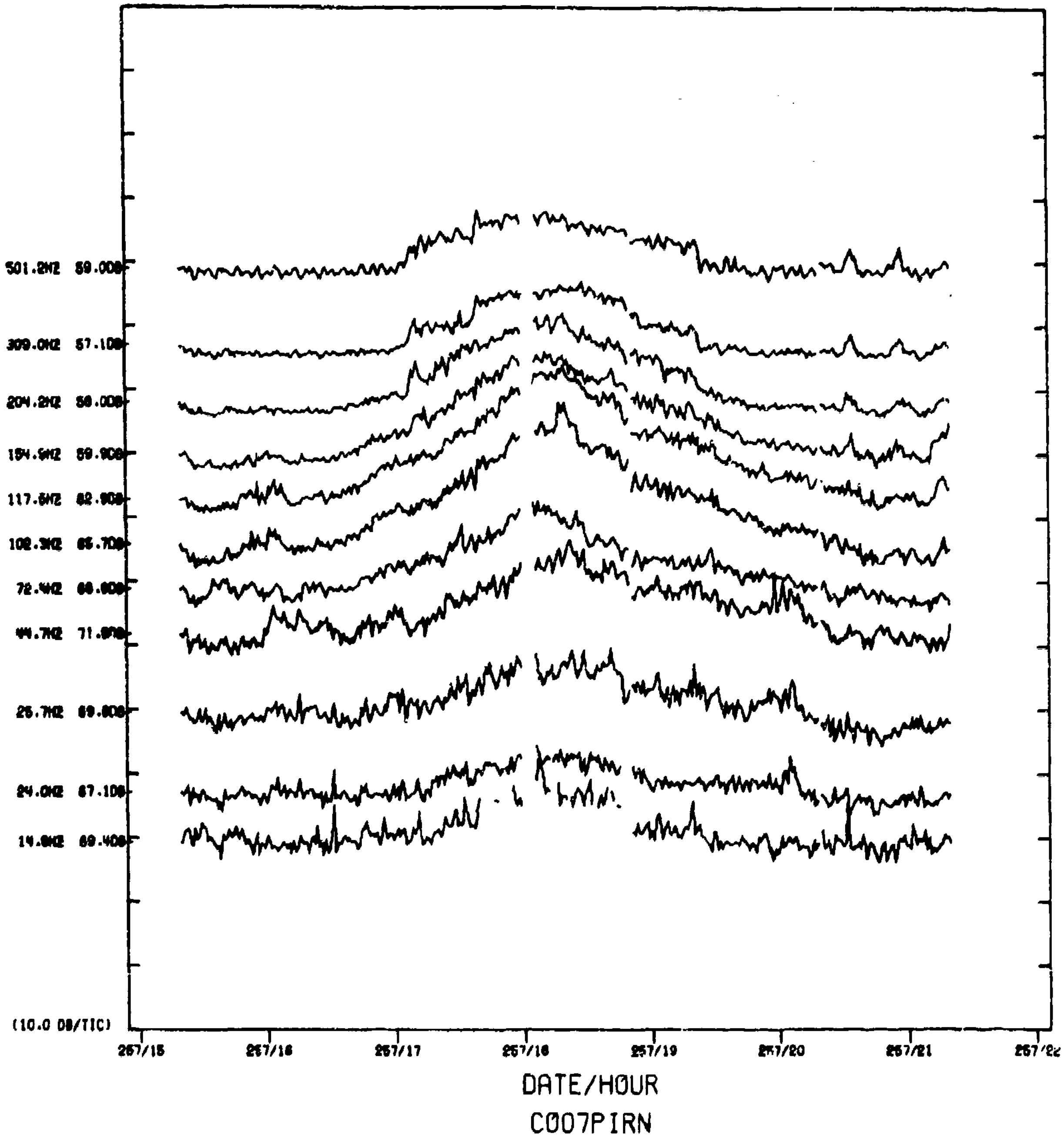

FIGURE C-1
PIRN TIME SERIES HYDROPHONE 07 (4459 m) (U)

ARL - UT
AS-77-360-P
KRP - DR
4 - 26 - 77

CONFIDENTIAL

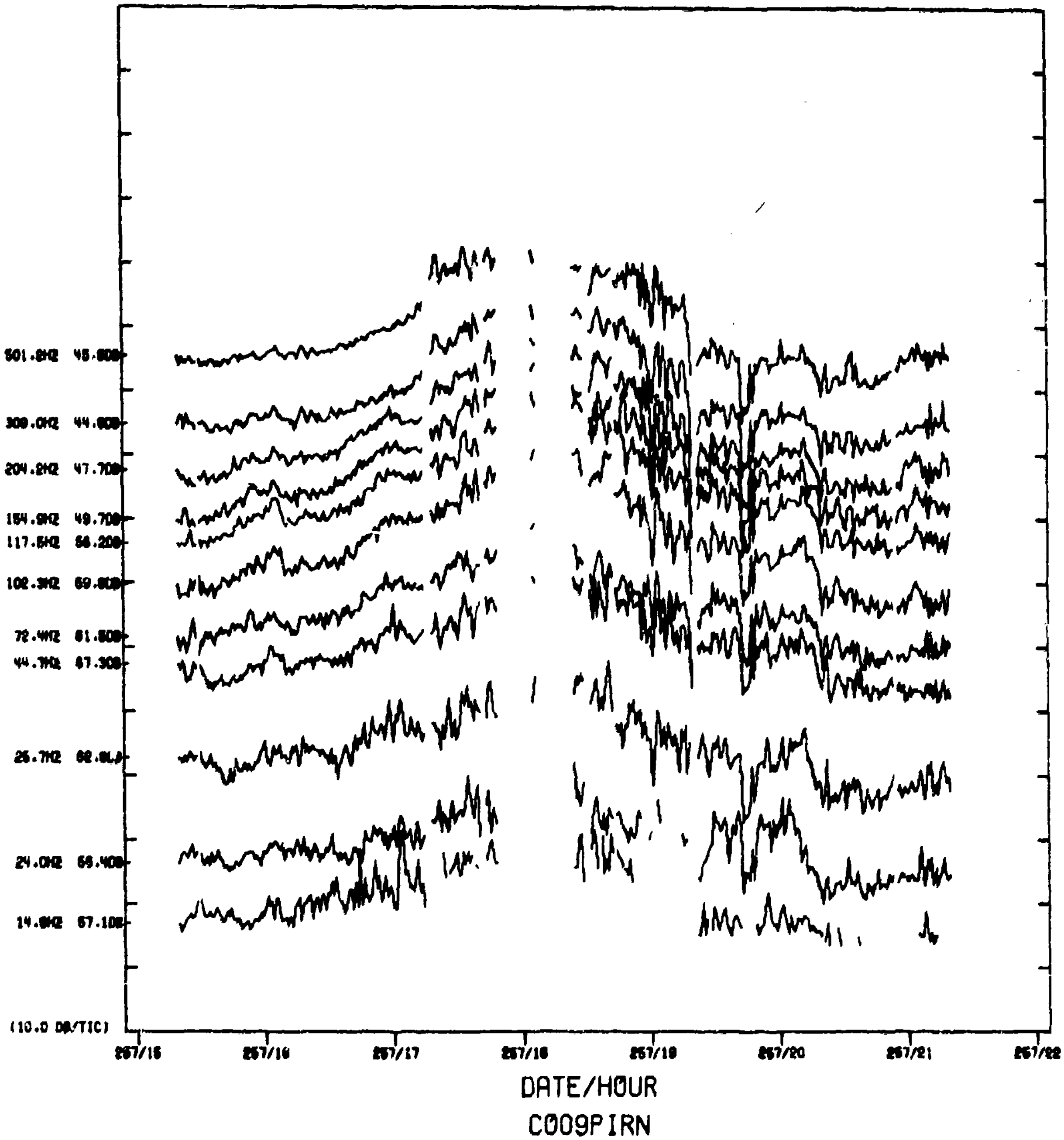

FIGURE C-2
PIRN TIME SERIES HYDROPHONE 09 (4681 m) (U)

ARL - UT
AS-77-361-P
KRP - DR
4 - 26 - 77

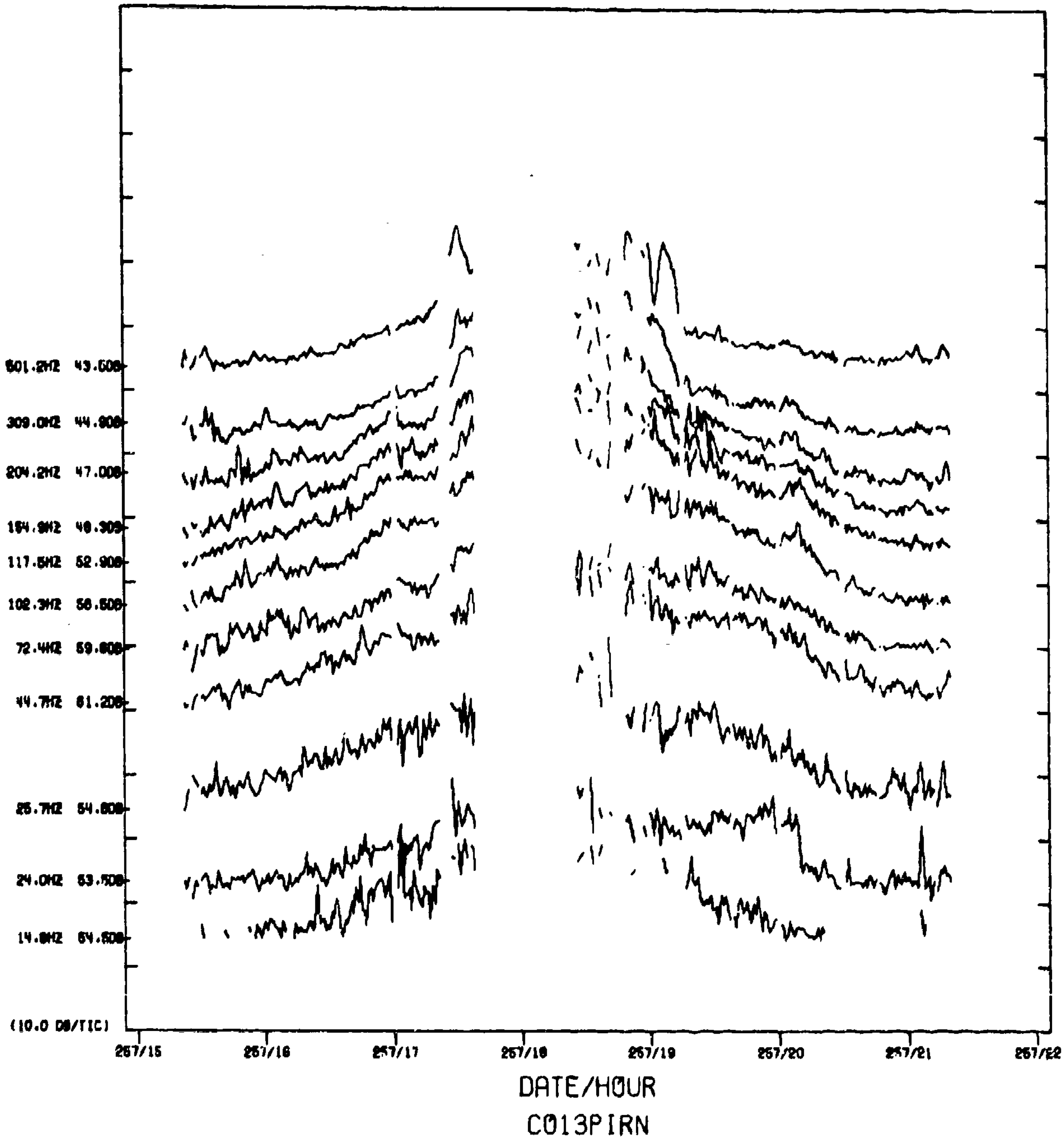

FIGURE C-3
PIRN TIME SERIES HYDROPHONE 13 (4853 m) (U)

ARL - UT
AS-77-362-P
KRP - DR
4 - 26 - 77

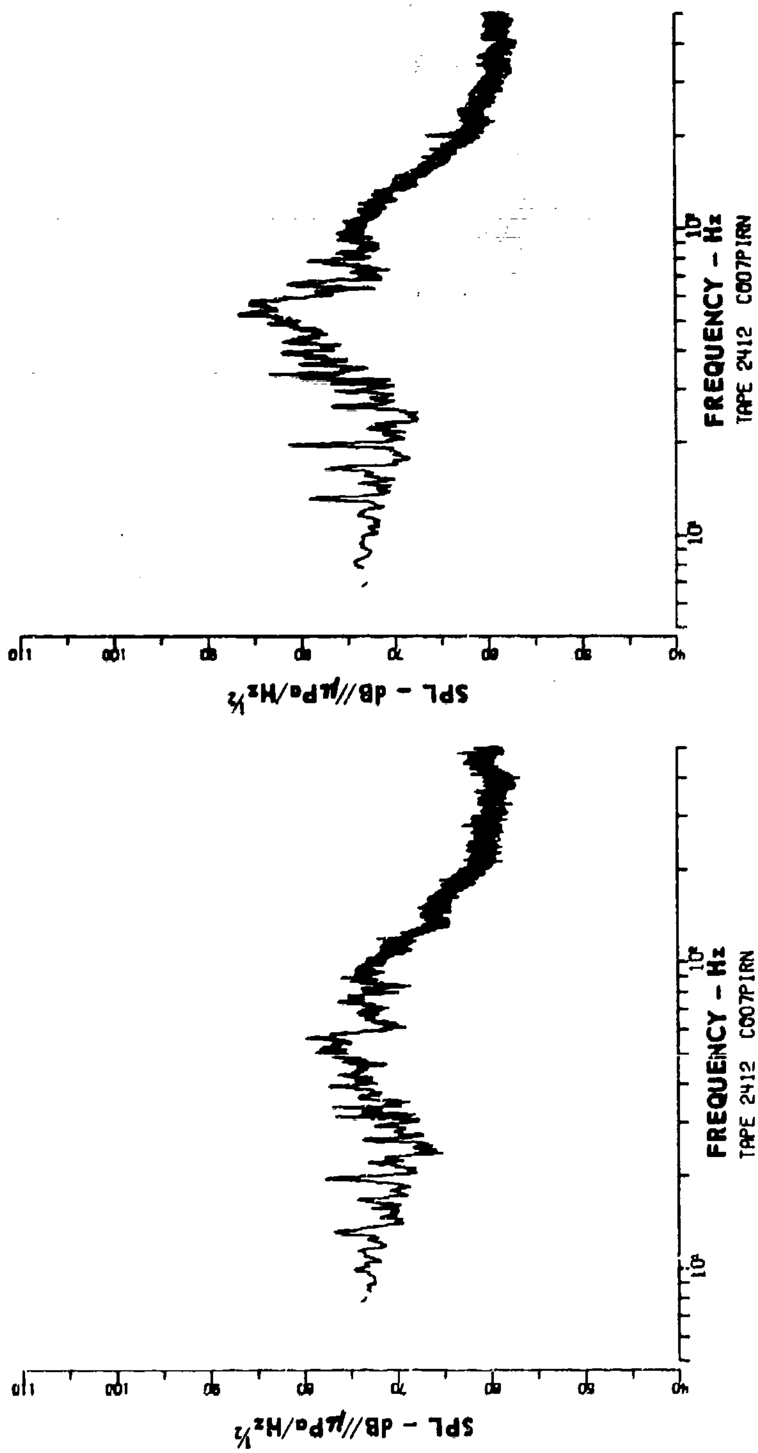

FIGURE C-4
PIRN SIGNATURES FOR HYDROPHONE 07 (U)

ARL - UT
AS-77-400
KRP - DR
5 - 3 - 77

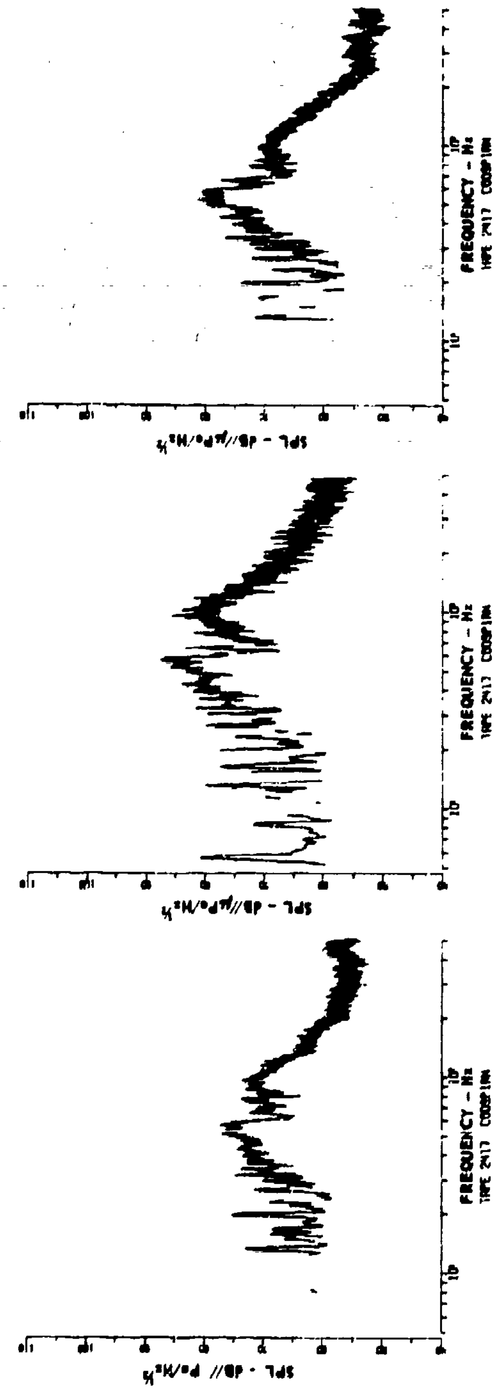

FIGURE C-5
PIRN SIGNATURES FOR HYDROPHONE 09 (U)

ARL : UT
AS-77-401
KRP : DR
5 - 3 - 77

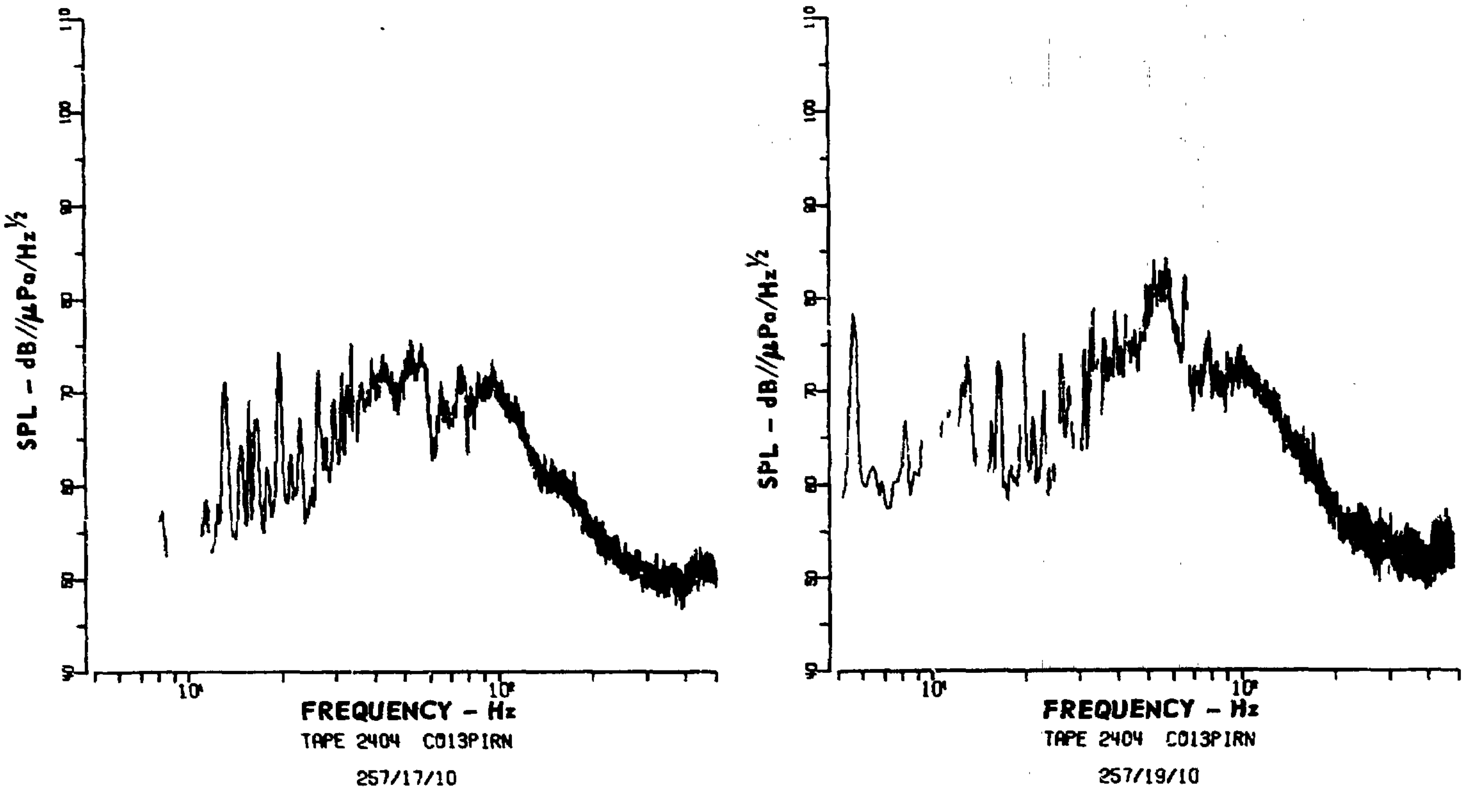

FIGURE C-6
PIRN SIGNATURES FOR HYDROPHONE 13 (U)

ARL - UT
AS-77-402
KRP - DR
5 - 3 - 77

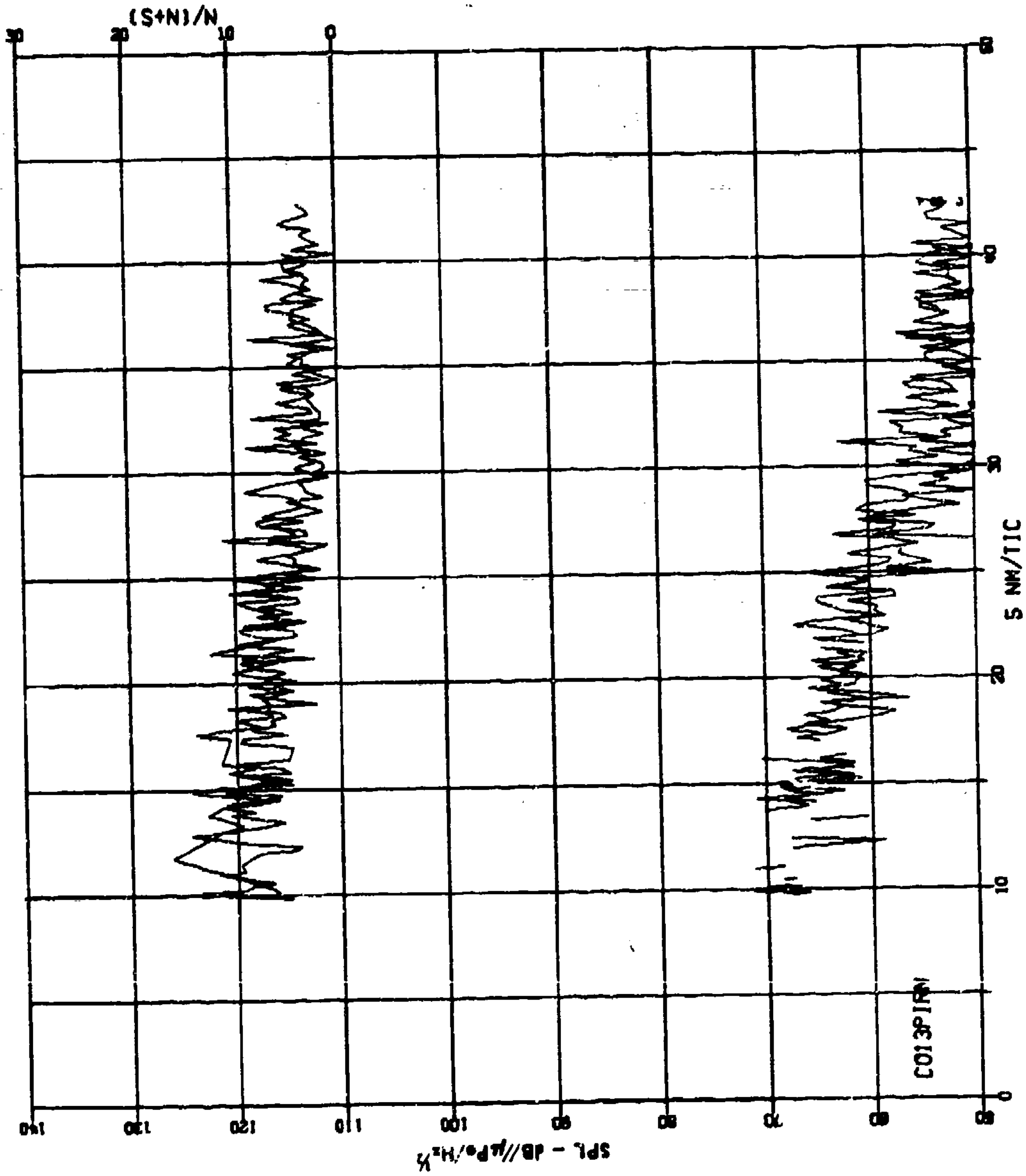

FIGURE C-7
RECEIVED SPL AS A FUNCTION OF RANGE
PIRN HYDROPHONE 13 (U)

ARL - UT
AS-77-410
KRP - DR
5 - 3 - 77

APPENDIX D

SDHT (ARAWAK)

(U) 1. Ship Description

Name: ARAWAK

Call Sign: SDHT

Type: General Cargo (19 kt)

Flag: Swedish

Owner: Rederiet for M.S. "Arawak"

Builder: 2 Eriksbergs M/V A/B Got (1966)

Dimensions: Length 149.23 m (490 ft)
Breadth - 18.98 m (62 ft)
Draught - 8.514 m (28 ft)

Displacement: 8023 tons gross; 4291 tons net; 8230 tons summer dead weight

Machinery: Oil, 2-stroke, single acting 8-cylinder main propulsion (10000 bhp) 4 each: 395 kW, 440 Vac generators

(U) 2. Measurement Data:

Time of CPA: 258/1100 (day/h)

Range at CPA: ≅4 nm

Speed of Advance: 18.3 kt

Wind Speed (at CPA): 5 kt

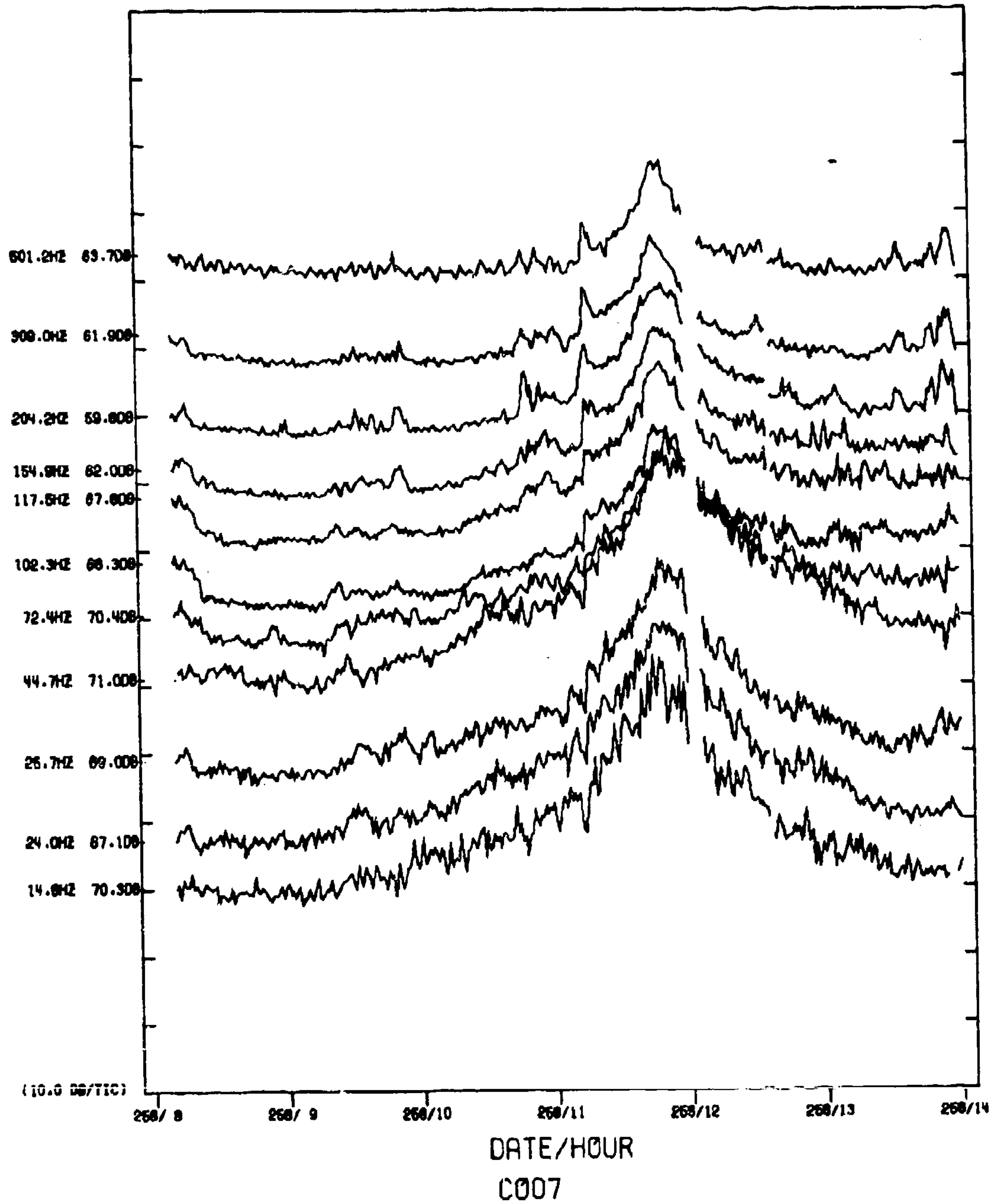

FIGURE D-1
SDHT TIME SERIES HYDROPHONE 07 (4459 m) (U)

ARL - UT
AS-77-363-P
KRP - DR
4 - 26 - 77

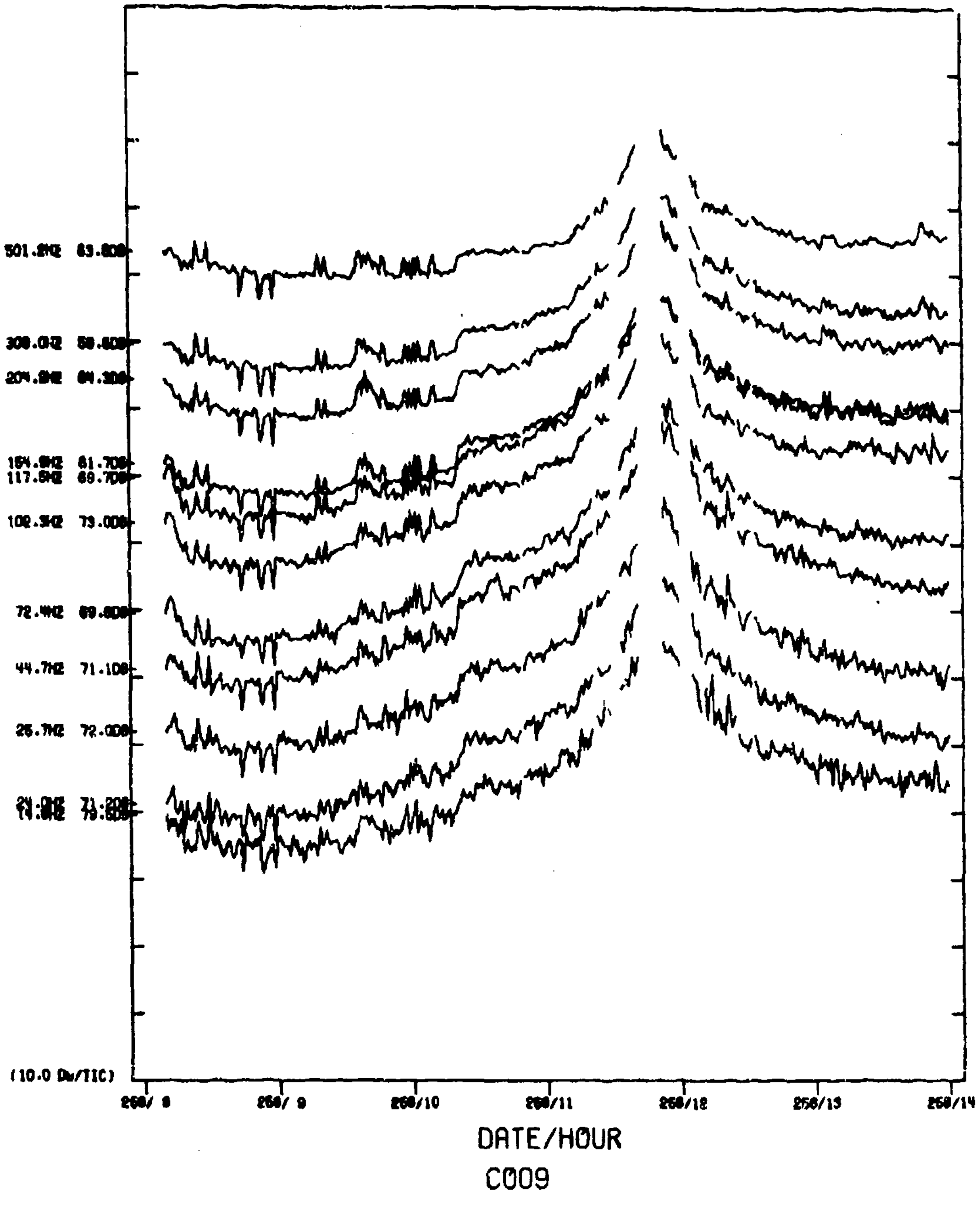

FIGURE D-2
SDHT TIME SERIES HYDROPHONE 09 (4681 m) (U)

ARL - UT
AS-77-364-P
KRP - DR
4 - 26 - 77

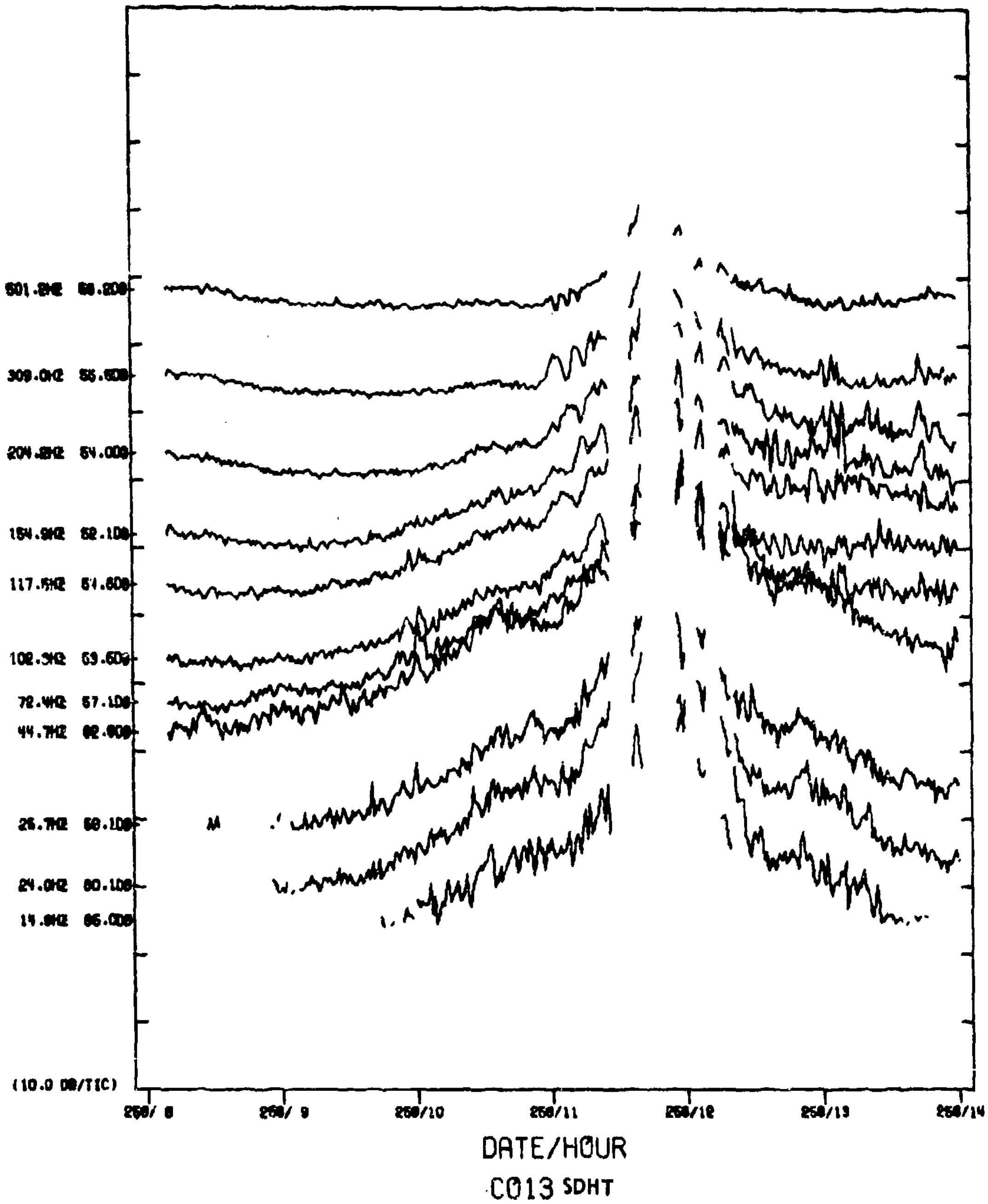

FIGURE D-3
SDHT TIME SERIES HYDROPHONE 13 (4853 m) (U)

ARL - UT
AS-77-365-P
KRP - DR
4 - 26 - 77

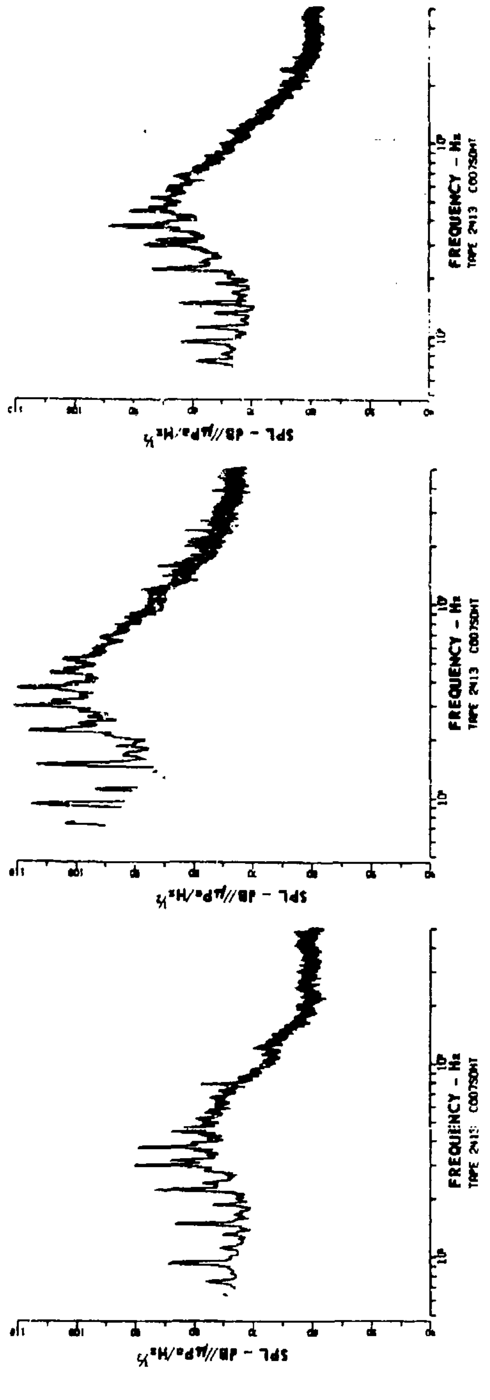

FIGURE D-4
SDHT SIGNATURES FOR HYDROPHONE 07 (U)

ARL - UT
AS-77-403
KRP - DR
5 - 3 - 77

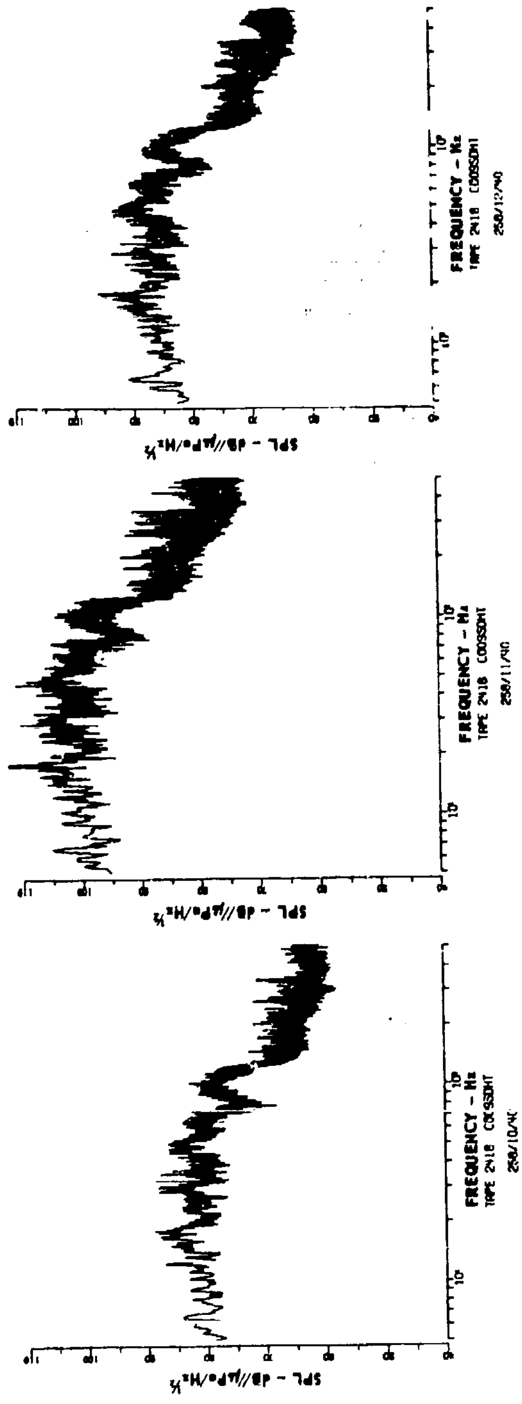

FIGURE D-5
SDHT SIGNATURES FOR HYDROPHONE 09 (U)

ARL - UT
AS-77-404
KRP - DR
5 - 3 - 77

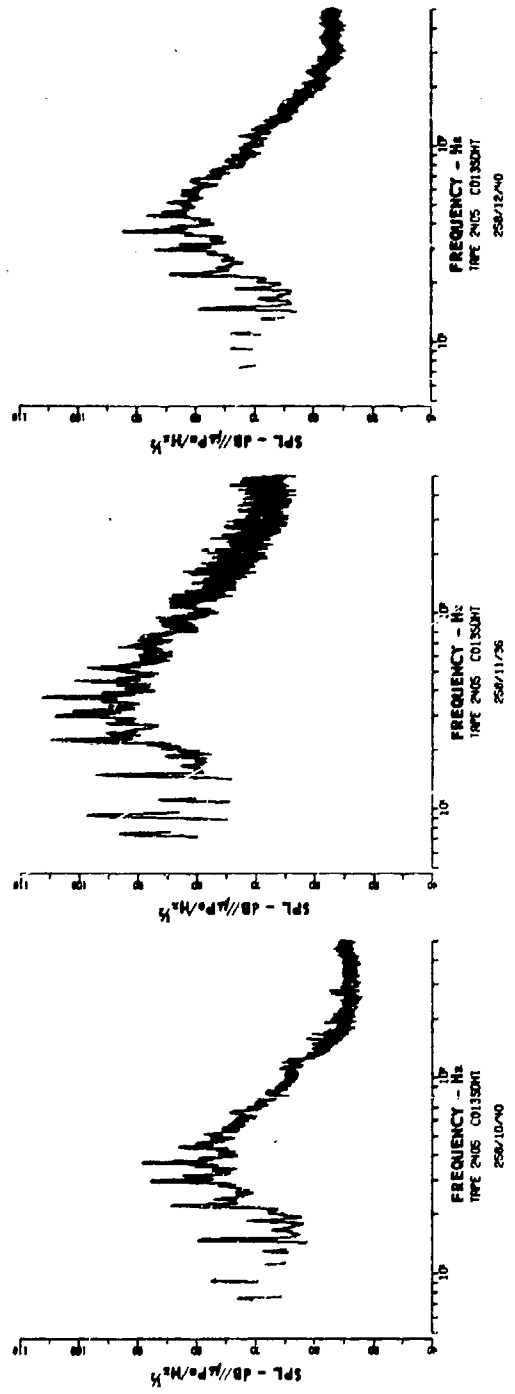

FIGURE D-6
SDHT SIGNATURES FOR HYDROPHONE 13 (U)

ARL - UT
AS-77-405
KRP - DR
5 - 3 - 77

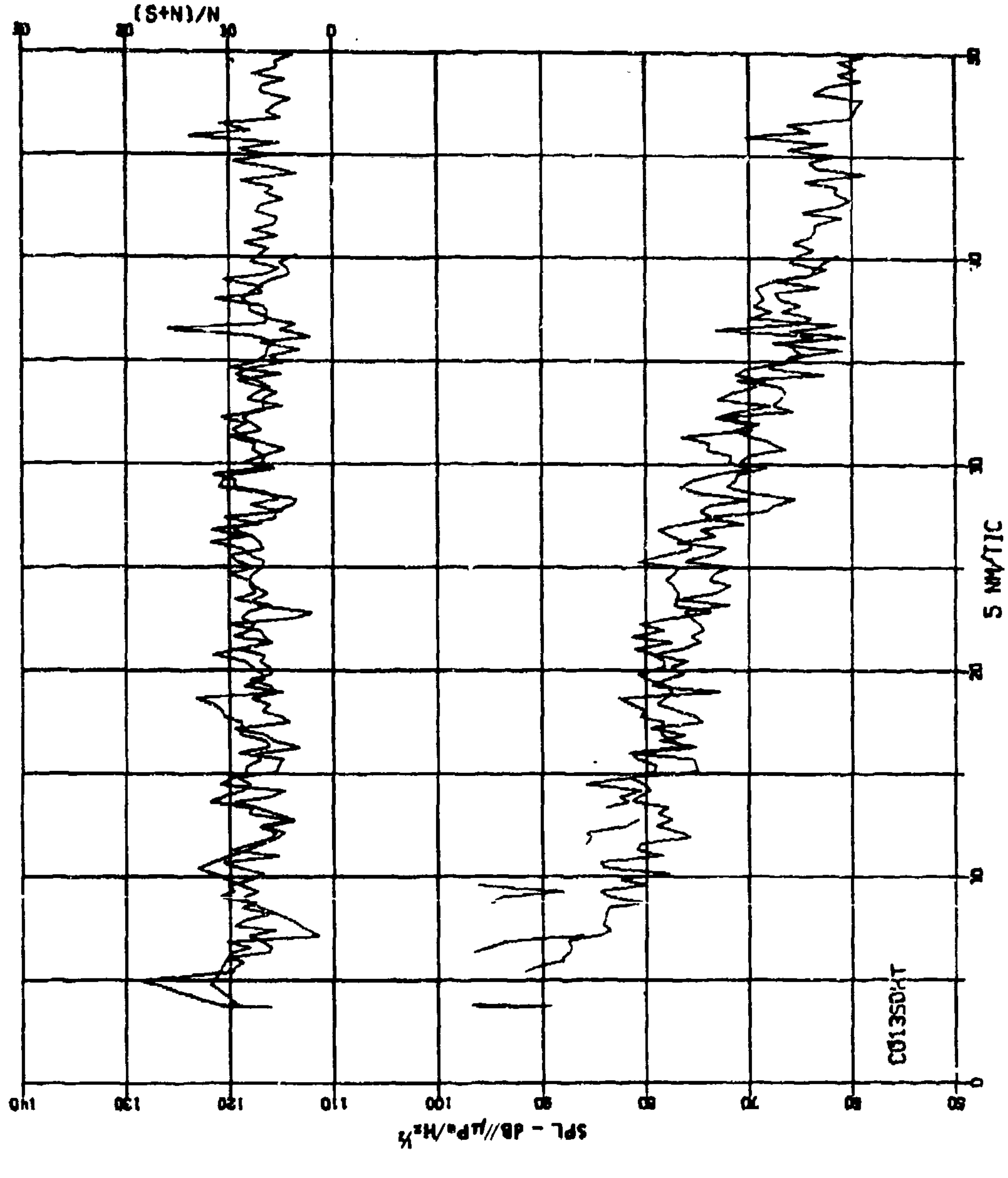

FIGURE D-7
RECEIVED SPL AS A FUNCTION OF RANGE
SDHT HYDROPHONE 13 (U)

ARL - UT
AS-77-411
KRP - DR
5 - 3 - 77

APPENDIX E

COMPUTATION OF PROPAGATION LOSS

(U) Of critical importance in the computation of source spectra for the events presented in this paper is the selection of a propagation (or transmission) loss model which can yield accurate predictions of propagation loss as a function of range geometry and frequency.

(U) The ARL:UT normal mode model that was selected consists of two basic application programs. The first program computes a set of normal modes, eigenvalues, and group velocities based on the specified parameters. The second program computes propagation loss and constructs graphical output of the sort shown in Fig. 4. In this drawing, the horizontal scale is 5 nm per major tick mark and the vertical scale is 10 dB per major tick. Since a major narrowband line appears near 25 Hz in all four of the ship signatures (presented in appendices A through D), that frequency was selected for calculating transmission loss. In the case of Fig. 4, a source depth of 6 m was selected as being typical of the merchant vessels whose signatures appear in the appendices. The receiver depth selected in Fig. 4 corresponds to hydrophone 13 in the CHURCH OPAL ACODAC configuration, or 4853 m below the ocean surface. Some of the CHURCH OPAL data indicates that surface mirror effects may also be present because of the shallow source depths. This surface imaging could be of significant value in reconstructing source depth information for each event.

(U) One of the parameters which must be specified when the ARL:UT normal mode model is used is the subbottom composition. Since no direct measurements of bottom loss were made during the CHURCH OPAL exercise and no cores were taken, the bottom loss characteristics were determined experimentally by fitting the received data structure with the theoretical propagation loss structure and adjusting the bottom parameters to obtain the closest fit between the two curves. This process is outlined in the following paragraph.

(U) It may be recalled from section II that time series plots were used to view the continuous cavitation spectrum for each of four events.

(U) TABLE E-I

TRANSMISSION LOSS PREDICTIONS:
ARL:UT NORMAL MODE MODEL VERSUS FACT

Transmission Loss at 25 Hz (dB)

	Range (nm)				
	20	25	30	35	40
FACT[1]	92	94	95	96	97
FACT[2]	96	98	98.5	99	100
ARL:UT Normal Mode	100	101.5	103	104	106
FACT[3]	110	110	111	110	110

Note: 1. Indicates Subbottom Composition Type 1 (perfect reflector)

2. Indicates S.C. Type 2 (50% reflector)

3. Indicates S.C. Type 3 (perfect absorber)

(U) To view the received sound pressure level as a function of range, the data for selected bands were replotted, as in Fig. 4. The 26.6 Hz band for event JEEO, hydrophone 13, was replotted as a function of range, in this case 5 nm per major tick mark to match the horizontal scale of the propagation loss curve. The data are obviously folded about CPA corresponding to decreasing range before CPA and increasing range after CPA. The S/N of the received signal as a function of range is also plotted in Fig. 4 to aid in interpreting the data which may be questionable (less than 3 dB S/N). The results of Fig. 4 represent the best curve fit obtained using this graphical method for determining subbottom composition.

(U) As previously noted, one of the advantages of using the ARL:UT normal mode model to predict transmission loss at ranges greater than 10 nm, at 25 Hz, is that it compares very well with both the Fast Asymptotic Coherent Transmission (FACT) model[8] and the Parabolic Equation (P.E.) model[9] currently being used at ARL:UT. The FACT model is a Navy interim ray-acoustics model designed for the computation of transmission loss as a function of range and frequency for specific source-receiver geometries. P.E. is a wave-acoustics model designed for computation of transmission loss as a function of range and depth at low frequencies. Table E-I is a summary of the transmission losses predicted by FACT and the ARL:UT normal mode model as a function of range for a source depth of 6 m and a receiver depth of 4853 m (hydrophone 13). Two extremes of bottom types were used in the FACT predictions in order to isolate a bracket in which reasonable transmission losses might occur. As expected, the normal mode model prediction and the "average bottom" FACT predictions fell well within the boundaries.

APPENDIX F

CPA DETERMINATION

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(U) One point of reference available in the ship-track data, for events of opportunity, is the closest point of approach (CPA). Several methods are available which will extract the CPA time and range information. These methods are (1) to examine the time series plots and look for maximum received SPL, (2) to use the known ACODAC location and the recovered ship track information for an analytic CPA determination, and (3) to use the Doppler shift information in the received signals to determine CPA.

(U) For the purpose of this document an approximate geometric method of determining CPA location and horizontal range from the receiver was devised as follows. Using the slope-intercept equation for a straight line in a latitude-longitude coordinate system

$$\theta = a + b\varphi$$

and given at least two navigation fixes near CPA, the constants a and b can be determined. An equation for CPA can then be derived using these two constants,

$$\varphi_1 = \frac{\varphi_o + \theta_o b - ab}{b^2 + 1} \quad ,$$

$$\theta_1 = a + b\varphi_1 \quad ,$$

where φ_o, θ_o is the receiver location and φ_1, θ_1, is the CPA position (see Fig. F-1). Once CPA location is known, the horizontal range at CPA can be calculated using spherical equations,

$$\theta = \cos^{-1}\left[\cos\varphi_1 \cos\varphi_2 \cos(\theta_1-\theta_2) + \sin\varphi_1 \sin\varphi_2\right] \quad ,$$

where

$\psi \equiv$ angle between two points on a sphere,

$\varphi \equiv$ latitude,

$\theta \equiv$ longitude,

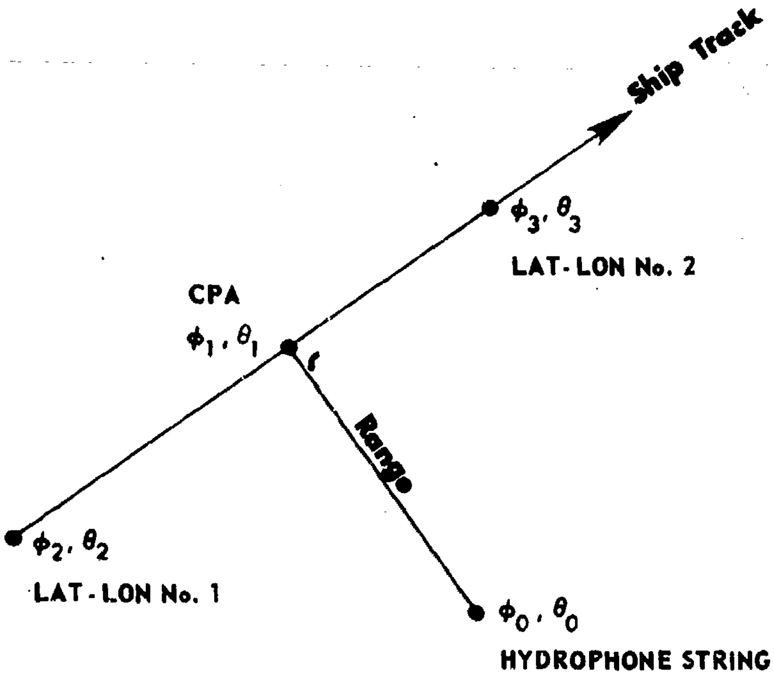

FIGURE F-1
HORIZONTAL RANGE GEOMETRY FOR SHIP TRACK CPA TO HYDROPHONE STRING

ARL - UT
AS-77-390
KRP - DR
5 - 3 - 77

(U) and one degree on the earth's surface is equal to approximately 60 nm. Table F-I is a summary of the pertinent ψ's and horizontal ranges at CPA for the ship tracks as well as each ship's SOA near CPA shown in Fig. F-2.

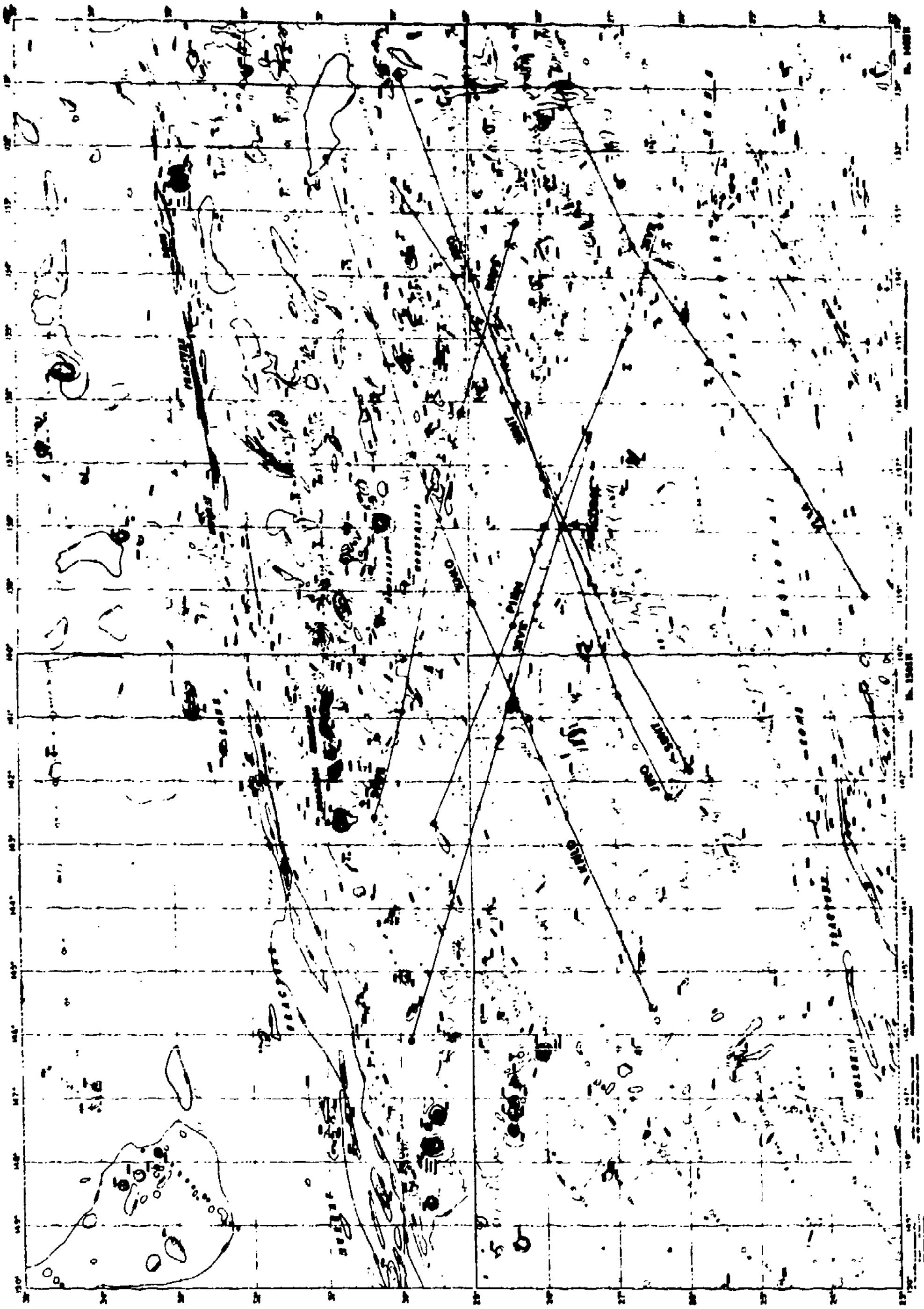

FIGURE F-2
BOTTOM CONTOUR MAP OF CHURCH
OPAL SITE SHOWING SHIP TRACKS (U)

ARL - UT
AS-77-391
KRP - DR
5 - 3 - 77

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REFERENCES

1. A. F. Wittenborn, "Ambient Noise and Associated Propagation Factors as a Function of Depth and Wind Speed in the Deep Ocean" (U), preliminary report prepared for LRAPP, NORDA, April 1976.

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1. In accordance with reference (a), a declassification review has been conducted on a number of classified CHURCH OPAL documents.

2. The CHURCH OPAL documents listed in Part 1 of enclosure (1) have been downgraded to UNCLASSIFIED and have been approved for public release. These documents should be remarked as follows:

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4. Questions may be directed to the undersigned on (703) 696-4619, DSN 426-4619.

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Author: Tomei, J
Originator: NORDA
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Date: 1977
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Title: LONG RANGE ACOUSTIC PROPAGATION PROJECT DATA BANK PROCEDURES WORKING GROUP REPORT
Classification: CONFIDENTIAL [?]
Author: unknown
Originator: Xonics, Inc
Ref. No.: unknown
Date: 1978

Title: NORTHEAST PACIFIC REGIONAL ASSESSMENT
Classification: SECRET (?)
Author: Hess, JA
Originator: Undersea Research Co
Ref. No. Vol 1: URC control no 393-77-S [or 590-3-77];
Vol 2: URC control no 588-8-77 Date: 1978

Title: UNIT INVESTIGATOR'S REPORT, M/V AMERICAN DELTA II OPERATIONS, CHURCH OPAL EXERCISE
Classification: unknown
Author: unknown
Originator: Xonics, Inc
Ref. No. Xonics TR-104-OSO
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Part 3 - Available Declassified and Unclassified Docs

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